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Valuing Changes in Hazardous Waste Risks: A Contingent Valuation Analysis

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Part I

Indirect Methods for Valuation

URBAN AMENITIES AND PUBLIC POLICY

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URBAN AMENITIES AND PUBLIC POLICY

Timothy J. Bartik and V. Kerry Smith*

I. INTRODUCTION

Our textbooks routinely describe consumption in terms that to the uninitiated must resemble a glorified conversion process -- money into satisfaction. Commodities are the intermediaries in this process. While this paradigm has been greatly refined in the nearly two centuries since Bentham, the most important recent contribution to the consumption analysis has begun with a recognition of the sterility of this "conversion process" view. The consumption of food in an attractive setting is a <u>different</u> experience than "gulping down" an equivalent repast behind one's desk (or television). Not all communities are alike. How often have we heard a community described as a nice place to raise children; or this city, town, or neighborhood has charm, character, or whatever? Why? What are households consuming when they choose an attractive setting in which to live or work? They are consuming amenities. While this term generally connotes location-tied goods, services, or characteristics that yield pleasure, we shall use it to designate location characteristics with either positive or negative contributions.

Amenities can be classified using many dimensions, such as geographic scale, degree of permanence, and the extent to which they are physically tangible. For example, one can describe the amenities of the United States in comparison to the Soviet Union or, more narrowly, the Northeastern portion of the U. S. in comparison to the Southwest. Further disaggregation to an individual city, neighborhood, or even a single block will be useful for many purposes. Amenities also differ greatly in how rapidly they change. For example, the crime rate of a neighborhood may sometimes drastically increase or decrease within a few years. In contrast, the climate amenities of Hawaii are likely to remain the same for the foreseeable future. Finally, some amenities are closely related to physically measurable phenomena, while others are quite subjective and difficult to define. For example, the air quality of a location can be physically measured, and will have some range of definite physical effects on those who live and work in that location. The "charm" of a historic neighborhood, on the other hand, is likely to be more difficult to objectively measure.

There is no doubt that the concept of amenities should be central to any realistic description of consumption. Nonetheless, our ability to empirically quantify their importance remains limited. Over a decade ago, Nordhaus and Tobin [1973], in their essay on the status of economic growth, boldly stated that the negative urban amenities were about five percent of GNP. By contrast, some three years later in a review article on environmental economics, Fisher and Petersen [1976] described such efforts as pioneering but to be taken with a grain of salt.

Both before and after the Nordhaus-Tobin study, numerous micro-economic studies have attempted to show the importance of amenities. Models based on property values and wages have enjoyed sufficient success to have spawned substantial theoretical literature on the appropriate methods for measuring and interpreting the effects of amenities on market price.

Before turning to our description of this work, we provide some indirect evidence of the importance of urban amenities and discuss the potential role for public policy in their provision. Table 1 summarizes per capita expenditures on activities that are often associated with urban amenities -- education, police, and air and water pollution abatement programs, as well as measures of the violent crime rate and air quality for 20 of the largest cities in the United States. In addition, based on the Annual Housing Survey, we report a summary of the households' expressions of satisfaction with their perceived amenities and the potential role of these amenities in their decisions to move. While indirect, fragmentary, and (in the case of the last set of variables) subjective, these data do offer clear evidence that amenities are important components of both local governments' decisions and of the factors affecting household attitudes toward their housing conditions and quality of life. Per capita expenditures for education ranged from twenty five percent to slightly larger than the per capita annual spending for national defense across these cities, while that for pollution abatement (air and water at the city level) ranged from two to thirty six percent.

As these data indicate, the public sector is involved in providing services that are clearly related to urban amenities. Police expenditures are an example. It must be recognized in these cases that what is controlled by the public sector may only bear an indirect relation to the amenity valued by households.

For example, safety of person and property would likely bear a closer correspondence to the amenities desired than police patrols or hours spent manning radar traps.

There are also examples where the amenity arises from private actions and the public sector seeks to regulate or influence these activities so as to affect what is available. Air and water quality cannot be "produced" by the public sector. Nonetheless, by limiting the emissions of pollutants into the atmosphere and water courses, the public sector influences their supply. In other cases, the mechanism is less clearcut. An amenity may be the result of a long process -- a charming neighborhood, or quaint college town are not necessarily created through the conscious actions of either private economic agents or the public sector. Often they are accidents of history. Nonetheless, local policies such as zoning, housing codes, and community development programs can influence the prospects for these amenities to arise and may maintain or destroy those which already exist.

It must be acknowledged that economic research on the relationships between policy and amenity supply, and between amenity supply and household satisfaction, can not yet provide precise estimates for policymakers. Nonetheless, as we shall discuss in detail, our theory and empirical results have confirmed the importance of urban amenities to households. Moreover, in some cases, the models have begun to play a role in the evaluation of policy alternatives. This is especially true for air and water pollution policies. Estimates of the implicit valuation of reductions in the ambient concentrations of pollutants have increasingly been a part of the benefit-cost analyses conducted for environmental regulations. While some may regard the use of the models amenity valuation in policy analyses as premature, these models may provide better information to policymakers than the available alternatives.

Our review considers first the economic modeling of household's decisions concerning amenities and the implications of this description for the use of observed behavior to evaluate their importance. We believe the hedonic property value and wage models provide the appropriate frameworks for analyzing amenities. The hedonic model emphasizes that households can choose amenities by choosing a location, and that these choices lead to equilibrium relationships between the market price of some commodities (such as housing) and amenities. There are two related questions about these hedonic models that we will discuss. The first is the appropriate interpretation of estimated equilibrium relationship between housing prices (or wages) and amenities. The second is the use of these models to estimate a household's valuation of changes in amenities.

Section III describes what we know based on intra and interurban analyses of the effects of amenities on housing values and wages. Rather than offer an exhaustive catalog of results we have attempted to summarize the points of consistency in available empirical studies and the areas where further research is needed. The last section discusses the research agenda implied by the work to date.

II. MODELING HOUSEHOLD SELECTIONS OF AMENITIES

The theoretical roots of the hedonic framework, which provides the basis for a structural analysis of implicit markets for amenities or other qualitative features of commodities, can be found in the equalizing differences explanation for differing wages by occupation originally posed by Adam Smith. Early contributions to hedonic theory were made by Court [1941], Houthakker [1952], Griliches [1961], Roy [1950], and Tinbergen [1956]. However, Rosen's [1974] pathbreaking essay was the first to provide a unified treatment of the modeling of implicit markets. Rosen's analysis provided a careful description of the role of individuals' utility and firms' profit functions in determining the equilibrium rates of exchange for heterogeneous goods. With it, there was a description of the relationship between the hedonic price function and the behavioral relationships that underlie it.

In simple terms, a hedonic price function describes the relationship between the equilibrium price of a commodity and its characteristics. It is based on the presumption that there exists a single market for a heterogeneous good, such as housing. Consequently, the equilibrium prices must assure that a matching of diverse demanders and suppliers with differentiated "types" of the commodity has been accomplished so that there are no incentives for any of the participating agents to change.

When it is reasonable to assume that individual economic agents (both households and firms) cannot influence the prices they face, then the hedonic price function is a double envelope

-- the highest bids of the households for goods with varying bundles of characteristics and the lowest offering prices of firms (or suppliers) making them available.[1] Equilibrium requires that each type of agent is paying (or receiving) his respective marginal willingness to pay (or marginal reservation price) for the last unit of each attribute of the commodity desired.

Rosen unified the diverse contributions to this area by highlighting the essential dimensions of the process leading to a set of prices and a market equilibrium for a heterogeneous commodity. At the same time, however, this simplification provided the potential for misinterpretation of the model and its relevance to individual applications. Thus, we will consider in detail the structure of the model when it is applied specifically to the problem of a household's housing and locational choices. An intra-city framework will be discussed first because the analysis can be confined to a single market, housing, under the assumption that employment decisions remain unchanged. Following this discussion we will treat the case where both the housing and labor markets can reflect the influence of amenities on households' decisions.

A. Household Choice in an Intra-City Framework

Households as demanders and firms (or landlords) as suppliers of housing with varying bundles of characteristics are assumed to be price takers. Moreover, in the intra-city framework, the household's employment decisions are treated as exogenous to their selection of a type of housing, including with it a set of site-specific amenities.[2] Thus we can describe the household as selecting a housing type to maximize utility subject to the available budget and existing set of prices for the housing types. These prices are generally assumed to be described using a function (i.e., the hedonic price function). More formally, the consumer will select a vector of characteristics (including amenities), $\underline{z}^a$, to solve the following constrained maximization problem.

$$\max_{\underline{z},x} U(\underline{z},s;\underline{D}) \quad \text{subject to } p(\underline{z}) + x \leq y \tag{1}$$

where $\underline{z}$ is a vector of housing characteristics (including amenities) that completely describe a house, p(.) is the hedonic price function for housing in the city, y is income, x is non-housing commodity (with a price of unity), and $\underline{D}$ is a vector of household characteristics that describe the reasons for differences in preferences across individuals. The housing supplier will choose a $\underline{z}^a$ and number of units to offer, M, to maximize profits in the problem

$$\max_{\underline{z},M} M(p(\underline{z})) - C(\underline{M},\underline{z};\underline{S}) \tag{2}$$

where C(.) is the cost function and $\underline{S}$ is a vector of supplier attributes that describes the reasons for all differences in supplier cost functions. It could include factor prices, variables measuring differences in firms' technologies and other factors affecting suppliers' behavior or constraints.

The behavioral outcomes described by these two maximization problems correspond to an individual's demand and a firm's supply function. Market equilibrium involves a matching of the desired housing types with what is offered. The existence of the hedonic price function is what assures that the matching will arise. That is, if we assume that there is a diverse population of demanders described by a distribution for the $\underline{D}$ vector of household characteristics and a diverse set of suppliers, then the price function is that transformation of characteristics to dollars which assures that the distribution of bundles demanded (based on the distribution of $\underline{D}$ across households) will correspond to the distribution offered (based on the underlying distribution of $\underline{S}$ across firms). Tinbergen [1956] appears to have been one of the first to offer an analytical solution for this matching. In general, analytic solutions to the problem for moderately complex descriptions of household and firm behavior have been intractable.

Rosen avoided the problem of deriving an explicit analytical form for the hedonic price function by specifying the existence of a continuous function to describe the equilibrium price set. This assumption permitted him to focus on the use of this equilibrium relationship in determining household's marginal willingness to pay and supplier's marginal offer prices for specific attributes of the housing bundle.

In particular, the marginal conditions from household and supplier maximization require that for each bundle of characteristics, $\underline{z}^{a}$, the marginal price of each attribute will be equal simultaneously to the marginal willingness to pay (or marginal bid) and marginal offer price for the member of each of the respective groups selecting and offering that bundle. This condition is given in equation (3) below.[3]

(3)
$$\frac{\frac{\partial U}{\partial z_j}}{\frac{\partial U}{\partial x}} = \frac{\partial P}{\partial z_j}(z^a) = \frac{\frac{\partial C}{\partial z_j}}{M}$$

Each element in Equation (3) is a function. Conventional descriptions of this result have used a diagram illustrating in two dimensions a cross-section of the n+1 dimensional equality implied by the equilibrium matching. Figure 1 reproduces this format using the bid (W) and offer (G) functions.[4]

The diagram shows bid curves and offer curves (i.e., the bid and offer functions holding utility and profit constant, respectively). In this illustration utility increases as an individual moves to lower bid curves in the diagram, because lower curves imply lower prices for the same housing bundle. Profits increase as a supplier moves to higher offer curves, because higher offer curves imply higher prices for the same housing bundle. The individual will seek to move to the lowest possible bid curve subject to the constraint of the price function. Similarly, a supplier will seek the highest possible offer curve subject to the same constraint. The particular demander and supplier shown in the diagram reach a maximum at a point z^a where bid, hedonic price, and offer curves are tangent.

B. Reversing the Logic: The Hedonic Price Function, Preferences, and Costs

The hedonic price function is a relationship that defines the exchange rates required for an equilibrium. A solution of the differential equations describing this matching implies that the price function will depend on the distributions assumed for the types of households and the types of suppliers. More specifically, since the price function brings the distribution of demands into correspondence with what is offered or equivalently the distribution of what is supplied into what is desired, the function can be described in terms of the parameters of either of these distributions together with the bundles offered or bundles desired. It would seem reasonable to expect that given knowledge of the hedonic price function and distributions of agents' characteristics and bundles, we could directly retrieve the underlying demand or supply parameters. However, our inability to find explicit solutions for the hedonic price function in terms of the parameters describing individuals' preferences and suppliers' cost structure prevents this approach.

These difficulties have promoted an alternative strategy in using the hedonic framework. This involves attempting to retrieve the marginal willingness to pay and marginal offer functions from the information provided in a hedonic price function. While this objective has provided a motivation for a substantial amount of economic analysis, it has not proved to be as direct (or simple) as Rosen's original description of the process seemed to imply.

To illustrate these difficulties, in Figure 2 we provide an alternative description of the equilibrium condition in terms of the marginal functions corresponding to the bid, offer, and hedonic price functions given in Figure 1. What we can observe (by the joint assumptions of market equilibrium and ability to specify p(z)) is the equilibrium prices for all possible housing bundles. This implies we can retrieve information on points of intersection of the marginal bid, offer, and price functions. Only the marginal price function is known. It is, by definition, the partial derivative of the hedonic price function. While our assumptions imply that Equation (3) is satisfied at each marginal price, this merely suggests that there exists a feasible matching at the given attribute vector. It does not imply that the same economic agents would be involved in each exchange implied by that matching. Indeed, the presence of distributions for D and S as explanations for the diversity in demands and offers implies that we must interpret these marginal prices as single points on different demanders' marginal bid (or suppliers' marginal offer) functions.

We emphasize that this problem is quite different from the simultaneity problem that is conventionally discussed in all demand and supply models. We are not implying that there is a simultaneity between some individual's marginal bid and another's marginal offer function which must somehow be disentangled. Both households and firms are price-takers. However, both face a nonlinear price function and an equilibrium condition that requires a matching. As a result, marginal prices, the bundle attributes, and the characteristics of individual suppliers (demanders) are all endogenous to the individual household's (firm's) choice.[5] Attempts to retrieve the marginal bid or offer functions must reflect this endogeneity.

C. Amenity Supply in the Hedonic Housing Model

Our description of the hedonic framework thus far has implicitly maintained that all characteristics, including amenities, are produced by individual housing suppliers. As we noted at the outset, a single specification of the process underlying the supply of amenities is unlikely to be very useful for most applications. The factors determining the supply of amenities vary rather substantially depending on the specific amenity under consideration. The examples we identified in the introduction were intended to illustrate the ways in which the public sector might influence this process, but also serve to reinforce this conclusion. It is somewhat surprising, given that concern over a public sector role in the supply process for amenities has motivated much of the research on valuation of amenities, to find that explicit analytical models of amenity supply are largely non-existent in the literature. Diamond and Tolley [1982], for example, define urban amenities as location-specific goods that are often nonexcludable once access to their location is acquired (and therefore have some features of a public good), but suggest only that their supply can be influenced by private economic agents and the public sector in complex ways.

In most cases, it is probably reasonable to assume that the supply of urban amenities is fixed over the time horizon that is relevant to the market equilibrium described by the hedonic price function. Clearly, government expenditures on public services -- education, law enforcement, fire protection, and the like, influence the supply of the amenities that are associated with these activities. However, the connection is neither direct nor sufficiently fast to warrant specifying a supply response mechanism. In other cases where regulatory decisions or the joint decisions of groups of economic agents together influence the amenities available, this assumption is even more defensible. History will matter particularly for the latter of these influences. To assume otherwise would add significant complications to our model of the equilibrium process. That is, the decisions of demanders and suppliers of housing about their location, housing consumption, and supply levels are made subject to some maintained pattern of amenity supplies within the metropolitan area.[6] The households that select each neighborhood, and their behavior and characteristics, together with the housing production choices of neighborhood landlords, affect each neighborhood's amenity supply and a pattern of amenity supply for the metropolitan area (as the collection of these neighborhoods) is the result. If we were to maintain that amenity supply was endogenous -- in assuming there was an "instantaneous" response in the quantity supplied of one or more amenities to the collection of household decisions and that households recognized that their decisions together with those of others influenced these supply outcomes -- then we must be prepared to change the equilibrium concept used to describe the market. The new description must either specify an information set that precludes strategic behavior or deal with the potential implications of strategic considerations for the equilibrium. Given the real world, time-sequenced nature of amenity supply, these seem, in our judgement, to be refinements in the models that are not warranted.

D. Marginal Bid Functions

Under the assumptions of market equilibrium and a correct specification for the hedonic price function for housing in a given area, estimates of this function permit the derivation of a collection of values of the marginal bids for each characteristic of a housing unit, including the site-specific amenities. These estimates are not confined to a single marginal bid (or willingness to pay) function. In order to estimate an individual's valuation of incremental changes in any particular amenity's level, we must use the relevant marginal willingness to pay function. A major portion of the literature in this area, and a considerable amount of controversy, has surrounded the process of retrieving this information.

There are several important dimensions of this problem which remain confused in much of this literature. They can be organized as responses to four specific questions.

1. Can some form of the marginal bid function be specified so that it is capable of empirical estimation?
2. Is there sufficient information in a single market hedonic price function to estimate the marginal bid functions for housing characteristics and urban amenities?

3. Assuming that marginal bid functions can be estimated, what is the appropriate interpretation of the benefit estimates derived from them?

4. Does non-linearity of the marginal price function limit the interpretation of the marginal bid functions?

The answer to the first question is yes, if one modifies the marginal bid function to remove the unobservable utility level. The marginal bid function used in Rosen's analysis and most subsequent work is essentially an analytical device comparable to a Hicksian demand function. It describes marginal bids holding utility constant. Just as it is possible to recognize that at any consumer equilibrium for a conventional good (i.e., with a constant price) the Marshallian demand intersects the Hicksian function evaluated at the utility level realized with the given prices and income, there will correspond to the theoretically defined marginal bid function an "uncompensated" function. That is, the process of substituting for the utility level realized at the optimum in terms of the utility function (or the indirect utility function) provides an expression for the marginal bid in terms of observable arguments. More specifically, if V represents the realized level of utility (4) describes the process analytically.

$$\frac{\partial W}{\partial z_j} = f(\underline{z},v;\underline{D}) = f(\underline{z},U(\underline{z},x;\underline{D});\underline{D}) = f(\underline{z},x;\underline{D}) \tag{4}$$

The marginal bid in this formulation depends on the chosen housing bundle, the level of non-housing expenditures, and demand variables.

The second question must be answered with a negative. A single hedonic price function alone is not sufficient to distinguish the marginal bid from the marginal price function. This point has been surrounded by confusion, since Rosen first described the process of isolating a marginal bid function as a "garden variety identification problem". It is not, as we have observed earlier, a question of distinguishing demand and supply motivations as some authors seem to imply (Rosen [1974], Epple [1982], Brown and Rosen [1981], and Brown [1983]). While there is interaction between demanders and suppliers in defining the hedonic price function as a description of the conditions required for an equilibrium matching, any one economic agent is an atomistic component of the process and therefore takes the price schedule as exogenous.

What needs to be distinguished for identification is each of the types of marginal functions. That is, each must be capable of being isolated from the marginal price function implied by the matching of all agents in the market equilibrium. This is a comparable logical problem to the classic identification problem referred to by Rosen, but it is not resolved by considering the operations of the market in the aggregate (as implied by Freeman [1979], Harrison and Rubinfeld [1978]) or by describing the actions of the alternative participants in the market (e.g., suppliers for the marginal bid or demanders for marginal offer).

In principle, the distinction can be accomplished with the use of additional information -- either in the form of functional structure or specific sources of variation in the marginal price function that are not associated with the diversity in marginal bids across households. The first of these can be as simple as postulating a different functional form for the marginal bid (or marginal offer) and the marginal price functions. This approach has often been accepted too quickly as the resolution of the problem, without an adequate justification for its maintained assumptions (see Linemann [1981], Harrison and Rubinfeld [1978] as examples). As Diamond and Smith [1982] observed in considering this approach:

> "Such a procedure will yield estimates, as it provides the additional constraint needed for identification of the demand equation. However, the estimates will be as arbitrary as the assumptions underlying them".[7]

By contrast, Quigley [1982] begins the process with the specification of a form for the individual's utility function and derived the marginal bid functions from it.

The second source of information for distinguishing the marginal bid and price functions arises from pooling separate estimates of hedonic price models across housing markets under the assumption each has a distinctly different hedonic price function. Given that the source of variation in the marginal price functions across markets is not associated with the levels of the demanders' characteristics, these functions, with sufficient variation, will "trace out" the marginal bid function for each characteristic. Of course, it should be acknowledged that resolution of the logical problems posed by identification does not imply that bias will not be present in estimates of the parameters of the marginal bid function. While we will return to this issue below, it is important to acknowledge at this stage that in contrast to the textbook identification problems (discussed primarily in terms of simple linear simultaneous equation models) the restrictions identifying one or more of the structural functions in a hedonic framework do not necessarily have a specific role in the definition of the estimators for structural equations such as the marginal bid function.[8]

Even if the issues associated with both of the first two questions can be resolved, the best which can be expected from benefit estimates derived from a marginal bid function (i.e., the answer to our third question) is the equivalent of an extremely restricted partial equilibrium measure of an individual's willingness to pay. For example, suppose the air quality in an area deteriorates. If moving costs or other adjustment costs prevent individuals from changing locations in response to this deterioration (i.e, we effectively hold all prices and quantities constant for the individual), then the marginal bid function for air quality can be easily used to analyze the costs of a marginal decline in air quality. The marginal bid function for air quality shows how the household's marginal valuation of air quality changes as air quality declines. By integrating between the before and after levels of air quality, an estimate of an individual's total valuation of the decline in air quality can be derived. Given exogenous information on the change in rents associated with the air quality change, the total valuation can then be compared with the changes in rent in the area to determine the net effects on the individual of the decline.[9] If one only wants to determine the total benefit losses due to the decline, the rent changes can be ignored because they only represent transfers between demanders and suppliers. But these simple benefit losses become incorrect if household relocation and the associated complete adjustment is allowed.

Finally, non-linearity of the hedonic price function (and the associated marginal price schedule for any individual characteristic) has important implications for the demand parameters in the hedonic model. These parameters cannot be used for as many purposes as those of an ordinary demand model. Consider, for example, an ordinary demand function in which quantity demanded is expressed as a function of the equivalent of a constant marginal price, income, and demand shift variables. This function can be used as a predictive relation given prices and income. By contrast, the demand parameters derived from a hedonic model cannot be used for prediction. Non-linearity implies the budget constraint cannot be easily parameterized by observed marginal prices. Both marginal prices and quantities are simultaneously determined (see Bartik [1983]).

Equally important, nonlinearity implies that few a priori constraints can be placed on estimated demand parameters.

For example, there is no presumption that there is a negative relationship between the quantity of a characteristic and the marginal bid for that chararacteristic. This is true even for the compensated marginal bid function. The second-order conditions for the individual's maximization problem simply require that the chosen bid function be "more concave" than the hedonic price function. This implies that the compensated marginal bid function must have a more negative slope than the marginal hedonic price function. But because of non-linearity, it is quite possible for the marginal price function for some characteristic to have a positive slope. Hence, the marginal bid function can increase with quantity of the characteristics involved.

E. Inter-City Models of Amenity Selections

The preceding models have been intended to describe a subset of a household's possible decisions in that locational decisions were assumed to be made within a single metropolitan area. The most important aspect of this assumption is that the implications of a household's decisions concerning the site specific features of a housing choice would be confined to the housing market. Employment decisions were assumed to be unaffected by these selections. Of course, this was a simplification. In addition to choosing amenities by selecting a residential location within a city, individuals may also alter amenities by their choice of a city in which to live and work. The choice of a city is more complicated to analyze than the within-city locational choice for several reasons.

First, the choice of amenities across cities involves two hedonic markets, the labor and housing markets, not just the housing market. Clearly, individuals consider not only a city's amenities, but its wages and housing prices in choosing a location. One would expect wages to vary across cities aside from any effects of differential levels of amenities as a result of variations in the local cost of living.[10] When we assume that locational decisions can involve movement among cities, the amenity choice problem facing individuals becomes more complex because the choice is now made subject to two hedonic price functions, one for the labor market and one for the housing market. These two functions arise as part of the requirements for an equilibirum matching involving both the housing and the labor markets simultaneously.

One of the most important issues that arises with this generalization is the extent to which inter-city amenity differences will be capitalized into wages versus rents. This will depend to a great extent on what is assumed about the response of labor demanders and housing suppliers. Each characterization of household adjustment in amenity selection will have implications for both the capitalization issue and the proper interpretation of the partial derivatives of each hedonic price function in relationship to an individual's willingness to pay for changes in site specific amenities.

A second complication with an inter-city choice framework arises in considering how to incorporate the variation in amenities within cities into the model. As we implied, the model could consider the simultaneous choice by a household of a job and a residential site, given whatever pattern of amenity availability occurs within and across cities. However, characterizing the within-city variation is not an inconsequential task, especially once it is recognized that measures of the levels of amenity variables are themselves often difficult to formulate. Consequently, the most common procedure in inter-city empirical studies has been to examine how wages and/or rents vary with the average amenity levels of each city, implicitly assuming either that the amenity levels are constant, or that they vary systematically within the city with another variable that is in the model, such as distance from the central business district (see Cropper [1981] as an example).

To date no model has fully addressed all these complexities. Roback [1982] and Rosen [1979] have proposed similar models of how amenities affect both sides of the labor and housing markets. However, both models ignore intra-city variations in amenities and assume a fixed city boundary.

Other researchers, such as Henderson [1982], and Clark, Kahn, and Ofek [1983], allow for intra-city variation in the amenity along with access to the central business district. In addition, these models allow for an endogenously determined city boundary. However, this second class of models does not develop how the firm's choice of a city will be affected by wage, rent, and amenity differentials. The theoretical work of this second group of researchers implies that, controlling for commuting costs, inter-city amenity differentials will be reflected in wages. While both sets of models are incomplete, they do serve to illustrate the implications of joint consideration of the labor and housing markets as well as the assumed behavior of firms in describing these markets' equilibrium conditions.

In order to understand their respective strengths and weaknesses, a brief outline of the essentials of each model will be discussed before turning to the empirical implementation.

Roback's model assumes that all workers have identical tastes, and a fixed labor supply, and all firms have identical cost functions associated with constant returns to scale (CRTS) production technologies. Workers' indirect utility functions can be specified in terms of the city's wage rate, land rental rate, and amenity levels, all assumed to be constant within the city. For equilibrium, worker's utility level realized must be constant (at k) across cities, as in (5).

$$(5) \qquad V(w,r,\underline{A}) = k$$

where w is the wage, r the land rental rate, and $\underline{A}$ the vector of amenities. Firms' costs are also assumed to depend on wage rates, land rents and the amenity vector. For equilibrium, firms' unit costs in each city must be equal to the product price, which is assumed to be a constant across cities. Normalizing this price to one yields Equation (6).

$$(6) \qquad C(w,r,\underline{A}) = 1$$

To describe the equilibrium wage and rent gradient, assume there is a single amenity and totally differentiate equations (5) and (6) with respect to A. Solving the resulting equations for $\frac{\partial w}{\partial A}$ and $\frac{\partial r}{\partial A}$ yields:

$$(7) \qquad \frac{\partial w}{\partial A} = \frac{C_A V_r - V_A C_r}{V_w C_r - V_r C_w} = \frac{C_A V_r - V_A C_r}{L(A) V_w / X} \gtrless 0$$

$$(8) \qquad \frac{\partial r}{\partial A} = \frac{V_A C_w - V_w C_A}{V_w C_r - V_r C_w} = \frac{V_A C_w - V_w C_A}{L(A) V_w / X} \gtrless 0$$

where all the subscripts indicate partial derivatives with respect to the subscript variable, L(A) is total land in the city with amenity level, A, (assumed fixed) and x is total production in the city.

Several aspects of the Roback analysis are important to highlight. First, while the framework explicitly identifies a firms' production decisions with the specification of cost function given in (6), her framework is essentially equivalent to that proposed by Rosen [1979].[11] His model postulated that households were self-producers of a consumption good with a fixed capital stock and thereby attached the amenity and productivity effects directly to the household. As we observed in Note 11, capital must be treated as fixed in her model and not "optimized out of the analysis" as she suggests. Roback's model specifies firms' production functions so that the burden of the proper assignment of resources is directed to the movement of households in response to the prices of location specific factors. While firms can, in principle, move, their decisions can be treated as complementary to the household selections.

We can also recast Equations (7) and (8) to gauge the relative impact of a given percentage change in amenities for wages and property values (rents). Assume that amenities are neutral with respect to a firm's costs (i.e., $C_A = 0$). Using the duality properties of C(.) -- $C_r = \ell/x$, $C_w = N/x$, with ℓ the land used in production, and N the labor we have:

$$(9) \quad \frac{\partial \ln w/\partial \ln A}{\partial \ln r/\partial \ln A} = \frac{\partial w/\partial A}{\partial r/\partial A} \cdot \frac{r}{w} = -\frac{rC_r}{wC_w} = -\frac{r\ell}{wN}$$

The absolute magnitude of the elasticity of the real wage response to amenities in comparison to the rents is equal to the ratio of land's share of costs relative to that of labor. Thus the responsiveness of wages to amenity changes relative to that of rents will depend on the assumed importance of land relative to labor (as a share of production costs net of capital). The most reasonable assumption is that labor will be much more important than land in production, and that rents are likely to be more responsive to amenity changes than wages.[12]

Finally, we can use the model to consider the implications of inter-city location decisions for the measurement of an individual's marginal willingness to pay for amenities.

Recall in the intra-city model, the marginal bid was equal to the marginal price derived from the hedonic property value model. Now two markets must be considered and neither marginal price is equal to the marginal bid (as demonstrated in Equations (7) and (8)). Solving for the marginal willingness to pay (V_A/V_w) indicates that both functions' marginal price schedules must be considered to estimate the marginal bid.

(10) $$\frac{V_A}{V_w} = y^* \frac{\partial r}{\partial A} - \frac{\partial w}{\partial A}$$

with y^* the equilibrium residential land consumed by the household.[13] Equation (10) indicates that the weighted sum (since $\frac{\partial w}{\partial A} < 0$) of the marginal price schedules is equal to the marginal willingness to pay. However, this result should not be surprising. The model ties job and location decisions together. In effect, a job and a housing location are jointly supplied with each amenity level. Thus (10) parallels the familiar public goods condition implying vertical addition of the marginal price schedules of the housing and labor markets. If this treatment of the decision process is plausible, then it implies that the issues associated with retrieving information on the marginal bid function can become more complex with inter-city models in that hedonic property value models will not provide point estimates of the marginal bids. Under ideal conditions, a hedonic real wage model, incorporating the effects of amenities on all prices that can vary with location and amenity levels will (for the ideal price index) yield a marginal price that equals the negative of the marginal willingness to pay for the amenity.

By contrast to Rosen-Roback, the Henderson and Clark, Kahn and Ofek models assume a flexible city boundary at which land rents must be equal to the agricultural land-rent. Controlling for commuting costs, at this boundary amenity differentials must be reflected in wage differentials. More formally, assume a monocentric urban model in which worker utility depends on wages, rents, amenities, and commuting costs. Commuting costs depend only on the distance of the worker's residence from the city center. At the city edge and a distance of $\bar{d}$, land rents equal the agricultural rent level r_a. In equilibrium, workers living at each city's edge must all have the same utility, or using a revised indirect utility function:

$$(11) \qquad V(w, r_a, \bar{d}, \underline{A}) = k$$

Differentiating (11) with respect to w, $\bar{d}$, and A, and rearranging terms yields (12).

$$(12) \qquad dw = -\frac{V_d}{V_w}\, d\bar{d} - \frac{V_A}{V_w}\, dA$$

That is, holding the radius of the city constant, wages should vary with amenities. This framework does indicate the importance of including some control variable for city size or area if one is estimating how amenities affect nominal wages. Most studies have implicitly done this by including a variable for population, which is strongly correlated with the city radius, or in some cases by including both population and population density as variables. However, these variables have usually not been interpreted as control variables for the commuting costs of the resident at the city edge. Under this interpretation, any variable that is positively correlated with city radius would be expected to have a positive effect on wages simply because workers at the edge must be compensated for the higher commuting costs.

One problem with the Henderson and Clark et. al. models is that the location decisions of firms are not examined. The derived conditions are clearly necessary for worker equilibrium. However, it is unclear why firms will be willing to pay a wage premium to compensate workers in large cities for higher commuting costs.

Neither the Roback-Rosen nor Henderson-Clark models fully addresses all the complexities in the inter-city amenity market. The Roback-Rosen model includes the demand side of the labor market, but ignores intra-city variations in amenities, commuting costs, and rents. The Henderson-Clark model allows for commuting costs and flexible city boundaries, but ignores firm behavior and does not examine how average city rents vary with amenities.

III. EMPIRICAL ANALYSES OF THE ROLE OF AMENITIES IN HOUSEHOLD DECISIONS

Implementing any theoretical model based on real world behavior and our available measures of the outcomes of that behavior is never a "picnic". There are inevitably compromises associated with attempting to meet the informational requirements of the model and to take account of the model's abstractions that may not be plausible for the application under study. A standard of perfection will always be a counsel of paralysis. To appraise their performance we will first consider some specific aspects of the estimation of hedonic models and marginal bid functions from them. Following this discussion we review the selection of the hedonic housing price and wage models, discussing the types of data, models, and findings that have been obtained in practice. In this exercise we have sought to identify the amenities which seem consistently important to the determination of market prices. Finally, the section closes with a discussion of the qualifying assumptions and their likely impact on the usefulness of the models' results.

A. Estimating Hedonic Models

While there are a large number of econometric issues that must be addressed in estimating hedonic models (and therefore might be considered here), we will focus on two aspects of the process -- the specification of the hedonic price function and the estimation of the marginal bid functions given a nonlinear price function.

Without theoretical guidance as to functional form, most empirical work has simply assumed some arbitrary functional form. In the hedonic housing literature, the most common functional form is the semilogarithmic, with the natural log of the housing price a linear function of the characteristics. This functional form assumes that a given change in characteristics has a constant percentage effect on housing prices.

Recently, a number of researchers have explored the use of the Box-Cox transformations procedure to develop the appropriate functional form for hedonic equations (Halvorsen and Pollakowski [1981]; Sonstelie and Portney [1980]; Bender, Gronberg, and Huang [1980]; Linneman [1980a]; Goodman [1978]). The Box-Cox transformation of a variable y is:

(13) $$y(\lambda) = y^{(\lambda-1)/\lambda} \quad \text{if } \lambda \neq 0$$
$$= \ln y \quad \text{if } \lambda = 0$$

This transformation can be applied to the dependent variable and/or to the independent variables in the hedonic equation. The transformation parameter, λ, is sometimes constrained to be the same across most of these variables, although this constraint is justified more by convenience than by theory.

The Box-Cox approach has the advantage of allowing for a more flexible functional form. This advantage is purchased at the cost of an additional set of parameters that must be estimated. Moreover, the Box-Cox maximum likelihood estimator has been recognized to be inappropriately defined. The transformation itself limits the range of dependent variable and therefore prevents the assumption of normality which is the basis of the "likelihood" function that has been proposed for estimating λ [12]. While the approach can be used despite this problem, one cannot appeal to ML theory for inference and interpretation of the properties of the estimates.

An alternative strategy for specifying a flexible functional form appeals to the notion of approximating any function with a Taylor-series expansion in all the characteristics. This approach can quickly become unmanageable if the number of characteristics is large, or if an expansion greater than second order is attempted.

Given the arbitrary nature of the specification for the hedonic price function, it is natural to consider the implications of mistakes. That is, how will misspecifications affect the performance of the hedonic framework? Any misspecification or omitted variables in the hedonic function will usually result in errors in measuring the marginal prices estimated from it, and hence the marginal bids. This measurement error will probably be correlated with the right-hand side of the marginal bid function, resulting in a potential source of bias for ordinary least squares (OLS) estimates of the marginal bid function. This correlation may seem unusual, because for most problems involving single equation models, economists feel free to assume that measurement error in the dependent variable is random. This assumption is inappropriate for the hedonic situation, as Brown [1983] has recently emphasized.

Consider the simple example of estimating the marginal bid function for z, which is assumed to depend on z, or

(14) $$\frac{\partial W}{\partial z} = C_o + C_1 z + \varepsilon$$

Since we do not observe the true marginal price, but some estimate of the marginal price, we cannot estimate (14), rather we can only estimate (15).

(15) $$\frac{\partial \hat{p}}{\partial z} = \frac{\partial \hat{W}}{\partial z} = C_o + C_1 z + \left(\frac{\partial \hat{W}}{\partial z} - \frac{\partial W}{\partial z}\right) + \varepsilon$$

$$= C_o + C_1 z + M + \varepsilon$$

where M is the measurement error. If M is correlated with z, OLS estimates of C_1 will be biased. This correlation should probably be treated as a likely outcome of most hedonic models. For example, suppose that the true marginal price function is

(16) $$\frac{\partial p}{\partial z} = B_o + B_1 z + B_2 S$$

but the marginal price function we calculate is based on an estimated hedonic price function that omits an interaction term between S and z. The calculated marginal price function would then be given as (17).

(17) $$\frac{\partial \hat{p}}{\partial z} = \hat{B}_o + \hat{B}_1 z$$

Under these assumptions, the measurement error term is given by (18).

$$(18) \quad M = (\hat{B}_o - B_o) + (\hat{B}_1 - B_1)z - B_2S$$

This term will be correlated with the right-hand side term z in the marginal bid function, even though S is not an appropriate argument in the marginal bid function. Moreover, M can be correlated with z even if S is uncorrelated with z as a result of the term $(\hat{B}_1 - B_1)z$.

A second source of bias in estimates of the marginal price has not to our knowledge been appreciated in this context. It can arise even with a correctly specified hedonic price function. Suppose that the true hedonic price function is a semi-log form as in (19).

$$(19) \quad \log p = a_0 + a_1 z$$

The marginal price for z will be given as:

$$(20) \quad \frac{\partial p}{\partial z} = a_1 \exp (a_0 + a_1 z)$$

Unbiased estimates of a_0 and a_1 do not assure that their substitution in (20) and prediction will yield unbiased estimates of the marginal price. Indeed, by Jensen's inequality, we know they will be biased for this case. More generally, any nonlinear marginal price function can be expected to yield biased estimates of the marginal prices. In some cases (semi-log and double-log) there are adjustments which can be applied to the predictions of the marginal prices to yield unbiased estimates (see Goldberger [1968]). For more complex nonlinear specifications, adjustments based on asymptotic approximations are possible.[15]

The second issue concerns the estimation of the marginal bid function, given unbiased estimates of the marginal prices. A substantial portion of the literature on the estimation of marginal bid functions has treated the identification and estimation issues together -- seemingly as if resolution of the first assured an absence of problems with the second aspect of the task. This is not correct. As we noted earlier, a nonlinear hedonic price function implies a nonlinear household budget constraint and the endogeneity of both the marginal prices and quantities of the characteristics selected by the household, including site-specific amenities. This nonlinearity has several further implications (beyond those discussed above).

First, estimates of marginal bid function will often merely reproduce the hedonic marginal price function (Brown and Rosen [1982]). This result will generally occur if all the available data come from one hedonic price function, and no functional form restrictions on the marginal bid function are assumed.

Second, the nonlinearity of the hedonic price function implies that OLS estimates of the marginal bid function (or inverse marginal bid function) will generally be biased (Bartik [1983]), and this bias does not disappear if observations are available from more than one hedonic function or if functional form restrictions are assumed. This nonlinearity implies that both characteristics and marginal prices are endogenously chosen by the individual. Although the overall number of different bundle types (or set of marginal prices) may be exogenous, the individual can still freely choose the characteristics and marginal price combinations he wants among those available.[16] Because of this endogeneity, both characteristic quantities and marginal prices (marginal bids) must be correlated with any unobserved traits of the individual (tastes) that affect his preferences for characteristics. For example, individuals with an unusually high taste (or marginal bid) for a characteristic would be expected to choose a greater level of that characteristic. This positive correlation between the residual and z_j would lead to a positive bias in OLS estimates of the coefficient on z_j in the marginal bid function for z_j.

Most researchers have focused on instrumental variable solutions to these econometric problems. However, there is an unresolved disagreement in the current literature over whether multimarket data is needed to provide sufficient instruments, although it is generally agreed that multimarket data is extremely helpful. One school of thought in this area argues that multimarket data are not needed if appropriate functional form restrictions on the marginal bid function are assumed. This avoids the problem discussed in Brown and Rosen. If this requirement is met, instrumental variables are then proposed for consistent estimation even with data from only one market. Brown suggests that the individual supplier characteristics originally proposed by Rosen will be appropriate instruments. Other researchers (Diamond and Smith [1982], Epple [1982], Palmquist [1981]) suggest that the housing characteristics excluded from the marginal bid function will be appropriate instruments. However, Rosen's supplier characteristics will generally be inappropriate instruments because they will be correlated with the residual in the marginal bid function (Bartik [1983], Epple [1982]). Because different types of suppliers provide different bundle-types, individuals with different tastes, by choosing their desired bundles, will tend to systematically match with those types of suppliers making such bundles. For example, individuals with a greater taste for a freshly painted housing unit will be more likely to choose units provided by a supplier who happens to be a professional house painter. The use of a variable for profession of the housing supplier as an instrument will therefore yield biased estimates. A similar type of criticism can be applied to the use of excluded housing characteristics as instruments. In general, if a variable is correlated with the marginal price and quantity of some characteristic within a hedonic price function, it is likely to be correlated with individual tastes for that characteristic because individuals with different tastes will choose different marginal prices and quantities.

With multimarket data, many more potential instruments are available. Several researchers have proposed as instruments dummy variables for the hedonic price function of the observation (Bartik, Brown, Diamond and Smith, Palmquist). For example, in housing studies one might use as instruments dummy variables for the metropolitan area or time period of the observation, on the assumption that the hedonic price function for housing exogenously varies from city to city and over time. These types of instruments are only appropriate if unobserved tastes do not vary on average from one hedonic price function to another.

B. Hedonic Housing Price Models

There have been an exceptionally large number of hedonic housing price models since the early contributions by Nourse [1967], Ridker and Henning [1967], Kain and Quigley [1975], and Anderson and Crocker [1971]. It would be both impossible and not necessarily instructive to provide another summary of all of these studies in the space of a few paragraphs. Several detailed reviews have been prepared (see Ball [1983], Smith [1977], Freeman [1979], Witte and Long [1983], and Ott [1982] as examples). Based on these reviews there are several general features of these studies that should be discussed. They include: the unit of observation (and with it the implicit difficulty of observing actual market transactions), the problem of market segmentation, and the issues associated with measuring the amenity variables.

Early hedonic models were based on census information generally using the census tract as the observational unit, the median property value as the measure of price, and measures of the "average" characteristics of the owner-occupied units in each tract as if they adequately described each unit within the census tract. Examples of this type of study would include Ridker and Henning [1967], Anderson and Crocker [1971], Polinsky and Rubinfield [1977], and Nelson [1978]. Clearly, because of the data used, these studies pose significant problems for the interpretation of their estimated hedonic price functions. The measure of price is a summary statistic of what households report as their estimate of the value of their home not the market price. Such responses can be expected to be imperfect measures of the market prices. Moreover, the use of summary statistics for both the price and the characteristics implies the equilibrium condition must be assumed to apply to measures of the "representative" housing unit. Indeed, there may not exist a housing unit which corresponds to the characteristics used to represent structure in any tract.

In some respects the issues posed by the use of these data are analogous to many aggregation problems in economics. However, in the case of hedonic price functions, we cannot (in most cases) derive an analytical expression for the price function as an equilibrium relationship, so there is little prospect of a refined analysis of the implications of aggregation or of deriving restrictions that could be imposed on the model to be estimated to reflect the effects of aggregation.

Furthermore, the use of aggregate census tract data does not allow examination of the effects of some of the most interesting neighborhood amenities. For example, aggregate census tract data does not permit a distinction between the effects of a unit's own housing quality and neighborhood housing quality. This is potentially important because the effect of the physical condition of other housing in a neighborhood on an individual unit's value is quite relevant for several federal and city community development policies.

A second class of studies has been based on the <u>Annual Housing Survey</u> with information on individual housing units, household reported property values (not market prices), characteristics of each unit, and household reported attitudes concerning the adequacy of neighborhood and town amenities (i.e., these are the micro counterparts to what was reported in Table 1). Linemann's [1980a] analysis of the prospects for a single national hedonic price function was, for example, based on these data. While an improvement on the census tract case, these studies rely on a price measure that the household perceives to be the current market price.

The final set of studies, and those with the best correspondence between the data and theory, is based on actual market transactions -- such as rents paid by tenants, or the local multiple listing services' records for sales of homes in a community during a particular period. In these cases a market price is available along with the structural characteristics of the site. The samples generally contain recorded sales over some time span. In periods of inflation of the general price level, it is unreasonable to assume all transactions can be pooled to correspond to the same nominal price relationship. Since the sample size involved often has not permitted partitioning according to selling season in each town, a simple adjustment to the market price for movements in the overall price index has been performed and the data pooled to estimate a single function.

Another problem in hedonic housing studies arises in the determination of the extent of the housing market. It is customary to assume that the housing market coincides with the metropolitan area but some observers have felt that the market might be segmented along racial lines or into smaller geographic units (Straszheim [1975], Sonstelie and Portney [1980], Goodman [1978], Schnare and Struyk [1976]). On the other hand, as we noted above, Linnemand [1980] and Butler [1977] have investigated the possibility that the housing market and, hence the appropriate hedonic price function, might be national in scope.

Many empirical problems arise in detecting market segments. The usual procedure has been to divide the city into the proposed market segments, and then perform an F-test for whether the hedonic coefficients in the different segments are significantly different. But there are several problems with this procedure. First, the hedonic coefficients could be the same or very similar across different markets. Second, the nonlinearity of the hedonic budget constraint implies that specification errors, not the existence of separate markets, could explain any significant differences in hedonic coefficients across proposed segments. The omission of higher order, interaction terms, or any other omitted variable from the hedonic estimating equation would result in biased estimates of hedonic coefficients. These biased estimates are likely to differ across market segments that are chosen by the researcher, such as the ghetto sub-market versus the rest of the city.

These problems suggest that rather than relying exclusively on empirical methods for uncovering market segmentation, an examination of factors defining the conditions of access to the market may be more successful. Racial discrimination is the obvious example, but there can be others. Some sections of a city become "company towns". The enclave of housing surrounding a university often exhibits this characteristic. Neighborhoods within communities can become associated with the employees of particular firms and this association can reinforce perceived limitations of access.

Another major problem in hedonic housing studies is the development of appropriate amenity measures. For most studies, site-specific amenity variables must be "attached" or matched with the records on housing units. As a rule, this attachment implies using city, neighborhood, or census tract averages as the measures of amenities. To the extent there is variation in the quality or character of the urban amenities at a lower geographic scale than can be identified in the matching, this procedure will lead to an errors-in-variables problem. A related problem is that information on many of the amenity measures considered to be important determinants of housing prices may not be available. This can lead to an omitted variable bias. For example, the average income of neighborhood residents is often proposed as a proxy measure for the overall status of the neighborhood (Leven et. al. [1977]). However, average neighborhood income is likely to be positively correlated with many of the omitted neighborhood amenities. Hence, the estimated effect of this variable on housing prices is likely to be positively biased.

Finally, the analysis may have available multiple measures of what is believed to be the same amenity. For example, one might have available police measures of the neighborhood crime rate as well as residents' perceptions of the crime problem. Inclusion of both measures raises problems. The variables are likely to be highly correlated which reduces the prospect for deriving precise estimates of the individual effects of each variable. Equally important, the presence of a "technical" measure of the amenity along with an individual's perception of the amenity raises questions with respect to how they are to be interpreted. The hedonic price function will be influenced by what individuals perceive the amenities to be. Presumably, the technical measure is an indicator of the information available to individuals for forming these perceptions. A single summary index of the perceived level of amenities may be an inadequate measure of the effects of the distribution of perceptions on the price function. This is an important practical problem because the theoretical framework assumes all individuals have complete (and the same) knowledge of the attributes of a housing unit. In practice, this is not the case. Consequently, a reasonable procedure would seem to be to summarize the information contained in the various measures into one variable.[17]

Of course, the above discussion implicitly maintains that households recognize local amenities without difficulty (i.e., there is no error in their perceptions), but the analyst trying to understand their behavioral decisions has incomplete information. To the extent households also have difficulty, then other variables may serve as "predictors" of the amenities they desire. For example, individuals can easily observe the exterior physical condition of houses in a neighborhood in which they are considering purchasing a home. This exterior physical condition may be a good predictor of the average income level of the neighborhood, which may be valued in and of itself or as a possible cause of school quality or of the crime rate. As a result, any estimated positive effect of exterior physical condition of homes in the neighborhood on housing prices may reflect not only the aesthetic value individuals place on exterior appearance, but also the value of exterior conditon as a predictor of other neighborhood amenities.

We now turn to an attempt to summarize the key points of consistency in the hedonic housing price literature. To keep the review manageable, the studies have been limited to those with the most extensive amenity information. Specifically, only studies that use individual housing unit measures and that have at least some information on three crucial amenities: (1) neighborhood physical condition; (2) crime rate; and, (3) school quality are considered. Once these restrictions are imposed, surprisingly few studies remain out of the hundreds that have been done over the past two decades.[18]

A comparison of the effects of individual amenities is difficult because each amenity is measured in different units. Moreover, the selection of a basis for measurement even within a given amenity can vary across studies. To allow for some comparability, we have standardized our summary of the measured effects of each amenity by considering the impact of a one standard deviation change in each amenity variable (within each study's data set) on the natural logarithm of the housing price. That is, we are approximating their percentage effect on housing prices of a standardized change in the amenity variable. A further advantange of this approach is that it allows us to ignore differences in housing price levels between the studies, and the distinction between flow (rent) and stock (home value) measures of housing prices. However, this procedure does limit our review to studies on which we could obtain information on the mean and standard derivation variables used in the hedonic analyses. For studies wtih multiple measures of the amenity variable, we only considered the measures with the largest percentage effects.

Table 2 reports the comparisons of the various studies.[19] This comparison is admittedly rough, but three general conclusions seem warranted. First, neighborhood physical condition usually has one of the largest percentage effects on housing prices of any neighborhood variable. This finding should be reassuring to the authors of current U. S. neighborhood policies, which primarily rely on physical improvement as the key to revitalizing neighborhoods. At the same time, we note that this larger effect of neighborhood physical condition than, for example, crime, does not necessarily mean that households place an enormous value on the appearance of the house next door. As we noted earlier, a neighborhood's physical condition may serve as a convenient visual signal to households of the overall quality of a set of neighborhood amenities.

Second, amenities seem to have smaller percentage effects on the price of rental housing than of owner-occupied housing.

Finally, the overall effects of amenities are within the range one might expect. Suppose that all neighborhood variables, both observed and unobserved, changed by one standard deviation. It seems unlikely, given the results in Table 2, for this to lead to less than a 10% change in housing prices, or more than a 50% change.

C. Hedonic Wage Models

The hedonic wage function has been a significant component of the empirical models of labor economics. In general these analyses have attempted to evaluate the effects of job characteristics on wage rates or earnings while taking account of the attributes of the employee.[20] More recently a parallel line of research has developed in which wage and earnings models were used to gauge the effects of site-specific amenities on compensation. As our analysis of the inter-city location model implied, we would expect both housing and labor markets to reflect the effects of amenities. Hoch [1972, 1974, 1982] appears to have been the first to attempt to measure the association between wages and urban amenities such as crime. However, Fuchs [1959] and Tolley [1969] anticipated these arguments by noting that city size (including presumably the positive and negative amenities that are associated with it) influenced money wages.

The type of data and measure of the dependent variables also serve to distinguish the wage models. For the most part these studies have used an average wage (or earnings) measure by occupation. These data were derived from BLS Area Wage Surveys or Census with the former reporting average hourly earnings and the later median annual earnings. Separate wage models were estimated by occupation with measures of urban amenities and labor market conditions. As a rule in these studies either a real wage measure was used as the dependent variable or an index of the cost of living was included as an independent variable in the wage functions. Most of these studies treat the estimated model as part of a simultaneous equation system. Hoch's work would be a notable exception in that his models are treated as reduced form equations.

Izraeli [1977] emphasizes the simultaneity in the determination of wages and the local price index; Getz and Huang [1978] argue that earnings, the cost of living, and the net migration are endogenous; and Cropper and Arriaga-Salinas [1980] interpret their estimates wage model as a labor supply function with real earnings, employment, and an index of air pollution as endogenous variables.

Overall the results of these studies are supportive but hardly overwhelming in the empirical evidence consistent with an inter-city model of household location and, with it, an association between real wages and urban amenities. The analyses can be criticized both on grounds that they are as incomplete in their treatment of job and individual characteristics and too aggregative with their use of a summary measure of wages. Only the air pollution, crime, and climate variables (as measures of amenities) appear to have a detectable influence on wages. However, these effects are not upheld over all occupations. For example, Getz and Huang found the violent crime rate to be a statistically significant and positive influence on earnings (after taking account of the cost of living) in four of the nine occupations considered. The measure used for air pollution (a principal component derived based on measures of particulates and sulfur dioxide) was a significant determinant in only one case and climate measures in three. The results for male laborers in Izraeli's [1977] analysis supported effects for air pollution and climate. Cropper and Arriaga-Salinas' study had similar findings with six of eight occupations exhibiting a significant effect for sulfur dioxide, five for a climate measure, and four for crime.

More recently three studies have considered the wage model with micro-level wage information -- Rosen [1979], Roback [1982], and Smith [1983]. All three are based on the current population surveys -- Rosen for 1970, Roback for 1973, and Smith for 1978. After controlling for individual characteristics, occupation, and industry characteristics, all three studies find clear support for effects due to crime, air pollution, and climate on wages. There are, however, some differences in the studies. Rosen's dependent variable was based on annual earnings deflated by a local cost of living index, while Smith's study used an hourly wage rate measure deflated by the cost of living index. Roback's model was based on nominal weekly wages.[21] All of these studies treated the models as reduced form equations and did not attempt to include the simultaneity effects specified in the models based on the aggregated wage measures.

Both types of hedonic wage studies support a role for amenities as influences to real wages. The findings based on the micro-level surveys are more supportive than those with the aggregative measures. However, this is what we would expect both as a result of the superior information (and associated ability to control for related determinants of wages) and, equally important, the sheer impact of the larger sample sizes in assuring the isolation of even quantitatively small effects on wages.

Thus, while the models provide support for an influence of urban amenities, can we go beyond this to measures of implicit valuation? To begin, it should be acknowledged that the success of wage models might be interpreted as an indication of the inadequacy of hedonic property value models for measures of the implicit valuation of amenities, because such estimates could be interpreted as ignoring the role of both markets as proposed in the Rosen-Roback model and demonstrated in Equation (10).[22] Alternatively, one might argue that the Rosen-Roback formulation is overly restrictive. By tying the household's adjustment to require simultaneous job and location changes to realize a change in amenities, it fails to capture the role of within city amenity variations and movements that do not imply a job change in the overall equilibrium condition. To date, such a model has not been developed.

From the perspective of benefit estimation for amenity changes, we have also focused all of our attention on marginal changes, and a special form of partial equilibrium analysis. Once it is recognized that a change in the level of any amenity leads to a simultaneous change in the prices (which vary with that amenity facing the individual), then the evaluation of the full welfare impacts implied becomes much more complex.

The literature has not come to grips with such problems. Simple comparisons of the estimated marginal valuations of amenities such as air quality between hedonic wage and single market property value models (as if the two could be treated as independent sources of this information) suggest much larger estimates from the former (the wage) than the latter for comparable pollutants (see Manuel et. al. [1983]). This finding is difficult to interpret given the limitations of the available theoretical models for interpreting hedonic wage and property value equations. Clearly, this is an area where further research is warranged.

D. Sizing Up the Assumptions and Practice of Hedonic Models

Clearly, the general comments at the outset of this section are relevant to the attempts to empirically implement the hedonic model. Freeman's [1979b] appraisal of the assumptions of the hedonic property value model provides a good starting point for describing some of these issues in generic terms. Based on his discussion as well as the subsequent literature, it is possible to highlight some of the most important of these concerns:

1. Do households and firms have the information and a common basis of perception to permit the relevant markets to direct the locational assignment of activities and the implicit valuation of the site-specific amenities associated with those assignments?
2. Is it reasonable to maintain the equilibrium assumptions required for the interpretation of the hedonic price function in housing markets where adjustment and transactions costs (which are ignored by the models) are substantial?
3. The hedonic price function in either the housing or wage market is an equilibrium relationship. As we noted earlier, analytical solutions for the equilibrium matching of economic agents have proved intractable for even moderately complex cases. Thus, the theoretical guidance available for the specification of these functions is limited if not non-existent. Therefore, can we detect the structure of these functions with reasonable assurance?
4. All of the analytical descriptions of household and firm behavior used to develop hedonic functions have been static, ignoring a household's consideration of the future and the prospects for resale of the commodity. To what extent does the abstraction from these considerations affect the use of the model to isolate

the effects of amenities and to estimate households' marginal valuations of them? And, finally,

5. Uncertainty is likely to be an important part of the household's decision making. Yet the models of their behavior have largely ignored its effects. Uncertainty enters the analysis for at least two reasons. Households' information concerning housing or job characteristics may be quite imperfect. Equally important, the site-specific attributes may include risks -- of health impairment due to exposure to air pollution or hazardous waste (see Harrison [1983]), of damage due to floods or other natural or man-made hazards (see Brookshire, et.al. [forthcoming]) and Nelson [1983]). The ability to "insure" against these effects will affect the household's marginal bid. Is certainty a good enough approximation given our other empirical problems with implementation?

For the most part, the theoretical (or even the experimental) information does not exist to provide answers on the importance of any of these concerns. Thus, an evaluation of their importance for the usefulness of applied hedonic modeling in valuing amenities is at this stage a function of professional judgement. It can therefore be expected to vary with the analyst involved. Before offering our judgement, it is important to acknowledge that many, if not all, of the concerns we identified would also be raised with virtually all empirical models in economics.

Despite these limitations, empirical models based on the hedonic framework do seem to be providing, with increasing consistency, indications of what are the most important characteristics (and the site-specific amenities) to households. Where the amenity is difficult to perceive and/or measure these models' ability is correspondingly affected. Thus, at the level of detecting the clearly identifiable (to households) amenities, the models do seem to have had success. Where there is difficulty in perceiving the amenities, the results are nonetheless consistent with the framework. That is, when we consider air pollution, for example, the models perform quite well when the air pollution problem is a serious one (e.g., Los Angeles, see Brookshire et.al. [1982]).

The issue of using hedonic models to estimate the marginal valuation of changes in amenities is a more difficult judgement call. To begin with, we will never know the true benefits of an amenity change. The available comparisons of property value models with direct questioning of individuals concerning environmental amenities has found agreement in that each set of estimates is within an order of magnitude of the other.[23] While this is not a high level of accuracy, it is as good or better than a large number of applied areas in economics. Ultimately, to evaluate the importance of inherent uncertainty in the estimates of the marginal values for amenities, we need to consider how they are to be used. It is probably fair to observe that for most policy-based uses, the level of uncertainty in other elements of the evaluation of a policy will be substantially greater than even fairly generous ranges accorded arise from the information that is available to implement empirical models. As a rule, the data used have been collected to serve other purposes and must be adapted to meet the needs of an empirical evaluation of the role of amenities. With such adaptation comes compromises whose ultimate effects on the quality of the empirical findings is unknown.

Of course, in discussing the performance of empirical models designed to test theory or estimate key parameters for policy purposes it is too easy to call for more and better data as the "solution" for improving the empirical work. We think this is unlikely to be realized. Of course, improved data will provide the basis for enhancing our understanding of the strengths and weaknesses of the hedonic framework. There are, however, some fundamental issues that require both theory and new data. In part, these were considered indirectly in the questions posed at the end of the last section. However, we believe four areas deserve repetition and emphasis. They involve: perception, equilibrium, empirical implementation, and policy uses of what we now have.

Perception

For the most part, the empirical analysis of amenities must rely on crude proxy variables, measured at an aggregate level, to estimate each amenity that is hypothesized to influence household or firm behavior. We have rarely asked how do households learn of school quality, available recreation, crime, air quality, etc. Do they have key indicators that serve as proxies for these variables or do they rely on others judgements (i.e., realtors, friends, business connections, etc.). Until we begin to realistically describe the process through which households (and firms) form these perceptions and acquire the information necessary to evaluate these descriptions, there will not be any resolution of the criticisms of the available proxy measures for amenities. Moreover, transferring estimates of the implicit valuation of these amenities to policy judgements will continue to be but a short step away from guesswork.

Equilibrium

The two markets used to estimate the effects of amenities are the housing and labor markets. For the most part past empirical studies have treated the former as local and the latter as national. Both types of studies have treated the markets as being in equilibrium where adjustment and transactions costs are negligible. We probably could not have picked cases where this is a less plausible assumption if some conscious effort had been devoted to the process. Nonetheless, the rather remarkably consistent track record of performance in both examples attests to the presence of the effects of amenities on market prices in these cases.

What remains is to judge how important departures from equilibrium will be to the theoretical interpretation and quality of empirical estimates of the implicit valuation of amenities. The hedonic model is a long-run model of household behavior. In some areas the average tenure in a home is three to five years, while in others it may be over a decade. It seems reasonable to expect that with existing empirical information and recent advances in modeling the role of adjustment costs for the dynamic behavior of the firm, our understanding of the equilibrium assumptions in this case can be enhanced.

Empirical Implementation

To date there has not been an unambiguously correct implementation of the hedonic method for measuring the demand for characteristics. All past efforts can be criticized for their treatment of either the identification problem or the simultaneity posed by a nonlinear price function. Moreover, if the Rosen-Roback form of the inter-city model is accepted then the interpretation of the marginal prices are also incorrect. Clearly an attempt to build an application based upon the recent theoretical analysis and econometric methods discussed for these problems is warranted. Equally important, it also seems reasonable to call for experimental work where analytical solutions are intractable to gauge the impacts of the common mistakes of past empirical studies. Perhaps it would be possible not only to learn from our mistakes, but to interpret correctly the estimates that are available rather than to discard them.

Prognosis for Policy

Theoretical and empirical research on urban amenities is clearly at the stage where we can identify what are the important amenities to households. While there are a wide variety of studies reporting implicit marginal valuations of amenities, there remain substantive questions with all of these estimates. They have received the most direct use in the valuation of air quality changes as part of benefit-cost analyses of environmental regulations. It might be argued that this case poses (except for extremely polluted area) one of the most difficult for households to perceive.

The available comparative evidence evaluating marginal valuations of air quality based on hedonic models with direct interviews suggests (as we noted earlier) that they fall within an order of magnitude of each other. While the hedonic results are often used as a benchmark for the survey, both are estimates conditioned on different sets of assumptions. In judging the value of estimates of the marginal valuations for amenities from hedonic models for policy purposes, one must consider the alternatives. Decisions that reallocate resources in an effort to change the amenities available will implicitly value these amenities even when these estimates are ignored. At this stage, there is no other "game in town" to replace them. Moreover, we feel their use is superior to nonuse. However, this does not imply that a strategy which treats these point estimates as reliable is warranted. Greater attention to incorporating the uncertainty due to the assumptions and statistical performance of the models is the only assurance the prudence will guide the interpretation of these valuation estimates, while research continues to improve their reliability.

FOOTNOTES

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1. In the case of housing, the suppliers are likely to be composed of firms and households, with the latter offering resale of homes and the former new housing units. For households the offer function is presumably influenced by the cost conditions for new housing of comparable attributes as well as by what might be termed the household's perceived valuation or reservation price for the unit. Lerman and Kern [1983] and Horowitz [1984] have begun the process of developing more realistic models of the bidding process and the role of sellers in that process.

2. There have been limited attempts to undertake hedonic housing models across cities. Butler [1977] and Linemann [1977] report analyses based on micro-economic data. By contrast, Smith and Deyak [1975] undertook an analysis with city-wide averages of housing prices using census information.

3. Equilibrium condition (3) can easily be confusing. It looks as if the individual demander and supplier are somehow interacting to determine the marginal price schedule, just as aggregate demand and supply for ordinary commodities determines

equilibrium prices. This analogy is misleading. Although the actions of all demanders and suppliers determines the hedonic price function, each individual agent faces an exogenous price schedule. No demand/supply simultaneity on the individual level is implied. Nonetheless, there are many econometric complications in estimating demand and supply parameters, as we discuss further on in the paper.

4. Both the bid and offer functions have been extensively used in the hedonic literature. The bid function is defined as the function $W(\underline{z};v,\underline{D})$ that solves $U(\underline{z},y-W;\underline{D})=v$, where v is some utility level. The bid function is a type of transformation of the utility function. Intuitively, the bid function gives the household's willingness to pay at some utility level for different housing types.

The offer function is defined as the function $G(\underline{z}, \pi, \underline{s})$ that solves $GM-C(\underline{z},M;\underline{s})=\pi$. Intuitively, the offer function gives the price at which the supplier is willing to provide different housing types.

5. Simultaneity in the matching of demanders and suppliers can lead to the appearance of a simultaneous determination of demanders and suppliers characteristics. What is involved is quite direct. Our model assumes that variations in demander characteristics ($\underline{D}$) give rise to the heterogeneity in demanded bundles of characteristics. A similar argument explains the diversity of suppliers' offers. Thus, it is reasonable to assume that the equilibrium matching will lend to a consistent pairing of certain types of demanders with specific types of suppliers.

This is a possibility, but not a certainty. It will depend on the nature of the distributions assumed for D̲ and S̲ across the groups of demanders and suppliers, as well as their respective roles in the bid and offer functions.

It is reasonable to suspect that elements from D̲ will be correlated with elements from S̲. This will affect the selection of instruments in estimating the marginal bid or marginal offer functions as we discuss in what follows.

6. This is the idea proposed by Tiebout [1956] as the basis for estimating the demand for local public goods.

7. Diamond and Smith [1982] p. 15. Of course, in general terms, this argument should not be surprising. All tests of hypotheses involve additional maintained hypotheses as McCloskey [1983] has so aptly described in his essay on the rhetoric of economics. What Diamond and Smith seem to be emphasizing is the completely arbitrary nature of the treatment of this problem in many past hedonic applications.

8. In the simplest textbook case, exclusion restrictions serve to identify linear structural equations and they involve predetermined variables. Such variables are assumed by definition to satisfy the conditions required for instruments in the definition of estimators for linear simultaneous equation models. Indeed, it is the presence of excluded predetermined variables in the first stage equations for right-hand-side endogenous variables that assures the consistency of two stage least squares (2SLS). See Kmenta [1971] for the standard treatment of simultaneous equation estimation and McCarthy [1971] for a discussion of the role of first stage instruments in the

consistency of 2SLS. In contrast, in the hedonic framework variables excluded from the marginal bid (offer) function, but included in the marginal offer (bid) function ae likely to be inappropriate instruments, as we will discuss further below. These variables will be inappropriate instruments because despite their exclusion from the marginal bid (offer) function, they are likely to be endogenous to the household's (firm's) choice, and hence correlated with the residual.

9. It is not the case that the hedonic price function can be used to predict tne new equilibrium price set after the change in air quality. See Lind [1973] and more recently Starrett [1981] for a discussion of the implications of the assumptions concerning the boundary conditions imposed on a model of household location and their implications for the capitalization of the benefits associated with public projects into residential property values.

10. Izraeli [1977] used this interdependency to argue for a simultaneous equation model noting that: "Money wages and the goods' prices are not independent variables. Wages as the main component of firms' cost of production, help determine the price of goods, and the vector of prices of goods is a variable affecting labor supply, thus helping to determine wages." (p.275)

We feel a connection is present but not a simultaneous determination. Labor is not the dominant component of cost for all industries. Indeed, for the manufacturing sector materials have the largest cost share. Of course, this relationship will vary with industry. Since adjustment is not instantaneous, the important implication is that the real wage is the relevant variable for a hedonic wage function.

11. Roback maintains that each firm's production function includes capital, labor, and land and that capital has been "optimized" out of the analysis. However, CRTS in capital, labor, and land, and this optimization process does <u>not</u> imply the CRTS in labor and land. For her analysis to be correct, one must assume, as Rosen [1979] did earlier, that each firm's capital is held constant.

12. This conclusion might change if city land area was endogenous. It would seem likely that land rents would go up less with an amenity increase if city land area expanded as amenities increased.

13. The weight assigned to $\frac{\partial W}{\partial A}$ is unity because the model assumes that a fixed amount of labor time normalized to unity is supplied.

14. For a discussion of the implications of this problem for the properties of the Box-Cox transformation, see Amemiya and Powell [1980].

15. It should of course be acknowledged that if the estimates of the hedonic price function are based on a maximum likelihood criterion, then the estimates of the marginal prices will be as well. Alternatively, it may well be that one is interested in estimates of the conditional median rather than the conditional mean for these marginal prices. In either of these circumstances, the bias issue may not be regarded as a serious problem.

16. Thus, assuming perfectly elastic or inelastic supply does

not solve the endogeneity problem in estimating hedonic demand parameters. This is counter to the claim made by Freeman [1979], Harrison and Rubinfeld [1978], and others.

17. One possibility is to include in the hedonic only one of the available measures. A second possibility is to include the first principal component of the alternative measures. A more complex, but less ad hoc approach would be to use the multiple indicator-multiple cause (MIMIC) models that are extensively used in psychometrics (see Goldberger [1974] for more information on MIMIC models). To our knowledge, MIMIC models have not been applied in the hedonic framework.

18. For reviews of this literature, see Freeman [1979], Smith [1977], Ott [1982], and Witte and Long [1983].

19. The specific references to the studies, and the equations and variables on which Table 2 is based, are summarized below:

(1) Follain and Malpezzi [1980]:

Based on Mean Estimates, pp 41 and 42

Physical Condition: V278

School Quality: School

Crime: Crime

Access: Shops

Noise: Traffic, Air

Overall Neighborhood Rating: V276

(2) Kain and Quigley [1975]:

Based on Semilog Eaution, pp 100-201

Physical Condition: Adjacent units for owners, Block face for renters.

School Quality: School Quality

Crime: Crime

Racial Composition: Proportion white

Neighborhood socioeconomic status: Median schooling

Access: Miles from CBD

(3) Barnett [1979]:

Based on Table 4, pg 17

Physical Condition: Composite rating of neighborhood quality

Access: Generalized access to employment

(4) Noland [1980]:

Based on Table 2, pg 11

Physical Condition: Composite rating of neighborhood quality

Access: Generalized access to employment

(5) Merrill [1980]:

Based on Tables II-2 and II-4, pp A-29, A-31

Physical Condition: Quality of blockface landscaping

Neighborhood Socioeconomic Status: Median income of census tract

Access: Distance from CBD

(6) Li and Brown [1980]:

Based on Model 2, Table 2

Physical Condition: On-site visual quality

School Quality: Test scores for 4th graders

Crime: Percent 16-21 years old who are high school dropouts

Neighborhood Socioeconomic Status: Median income

Air Quality: Sulfur dioxides

Access: Distance to CBD

(7) Bartik [1982]:

Based on Table 7-2, p 184

Physical Condition: PHCON

School Quality: SCHOOL

Crime: CRIME

Racial Composition: PCTW

Access: ACCESS

Noise: CONG

(8) Mark and Parks [1978]:

Based on Equation 4

Physical condition: RENTPC

School Quality: EXPPUP

Crime: CRIMRATE

Racial Composition: ADJNONPC

Neighborhood Socioeconomic Status: MEDY

Standard deviations are calculated from Little [1976].

20. For a review of the early literature on the use of hedonic wage models to estimate the effects of job characteristics, see Smith [1983]. A more recent update to this can be found in Triplett [1983].

21. Roback noted that a real wage would have been preferable, but indicated that the lack of availability of a local cost of living variable for all of the SMSA's in her sample prevented its use.

22. Of course, it should also be acknowledged that this

framework maintains that the only mechanism for adjusting amenities is by the household changing both its residential location and job. If within city and between city adjustment were considered as possible alternatives with varying adjustment costs, then one would expect a more complex equilibrium condition. Moreover, that equilibrium would likely imply removal of the prospects for arbitrage in acquiring amenities through the two potential types of movements.

23. See Brookshire et. al. [1982] and Desvousges et. al. [1983].

Table 1. Expenditures and Amenity Levels for Twenty Largest Cities

City	Amenity Related Expenditures (per capita)				Measured Air Quality[d]			Perceived Neighborhood Amenities % Reporting Undesirable[e]		Violent Crime Rate
	Education[a]	Police[b]	Air Quality[c]	Water Quality[c]	TSP	SO_2	Ozone	Neighborhood Conditions	Neighborhood Services	
New York	420.31	107.91	.58	36.62	52	34	10.7	89.3	40.8	2.22
Chicago	441.45	121.72	.84	17.80	69	34	6.9	79.8	41.9	.85
Los Angeles	499.62	125.66	.01	11.67	105	32	64.8	57.6	46.8	1.74
Philadelphia	378.12	100.12	1.01	88.91	53	51	8.2	82.6	39.2	1.04
Houston	253.96	75.04	.91	63.85	76	--	26.8	84.3	39.0	----
Detroit	441.38	148.35	----	134.77	75	30	7.1	66.4	55.4	1.94
Dallas	294.86	72.65	.21	58.83	61	--	1.1	50.7	39.1	1.36
San Diego	346.09	60.84	----	41.85	73	7	8.1	82.8	55.9	.73
Phoenix	419.76	87.51	----	49.49	--	--	1.1	54.3	54.8	----
Baltimore	319.11	103.80	.50	43.39	59	--	10.7	54.3	54.8	2.22
San Antonio	126.11	47.17	.23	40.59	52	--	0.0	92.0	48.0	.57
Indianapolis	192.99	58.26	.62	119.34	67	--	2.1	89.9	48.0	.98
San Francisco	237.02	105.00	----	177.89	51	7	2.5	85.7	43.2	1.74
Memphis	286.95	74.78	----	45.35	69	--	----	42.4	41.7	1.08
Washington, DC	437.84	179.16	.84	139.36	52	38	17.0	58.0	53.1	2.28
Milwaukee	453.58	95.22	----	68.48	60	53	9.1	86.5	50.4	3.42
San Jose	------	58.67	----	32.25	--	--	----	----	----	4.12
Cleveland	405.00	123.19	2.63	106.65	73	56	22.7	89.3	37.8	12.43
Columbus	------	79.49	----	72.43	50	--	4.1	90.2	45.7	5.26
Boston	464.98	125.87	.12	43.15	53	35	6.0	67.1	50.2	14.07

Table 1: continued

a These estimates are for primary and secondary educational expenses from the Digest of Educational Statistics, 1982, for the 1979-80 operating year.

b These estimates are taken from the County and City Data Book for 1983 and are for 1981 expenses.

c These estimates are based on the total dollar expenditures by each city for fiscal year 1980 and are taken from the State and Local Government Special Studies, No. 103; Environmental Quality Control

d These figures are taken from an unpublished summary of the indicator values for five pollutants in 102 urbanized areas prepared by the Environmental Protection Agency for 1978. The reported data have been checked with state records to assure consistency between federal and state measures of air quality.

TSP refers to total suspended particulates and is measured for the urban monitoring sites with complete data by the annual geometric mean averaged across all sites in micrograms per cubic meter.

SO_2 refers to sulfur dioxide and is measured for the continuous urban monitoring sites with sufficient hourly data by the annual arithmetic mean averaged across sites in micrograms per cubic meter.

Ozone is measured for the urban monitoring sites with sufficient seasonal data. In this case, we report the estimated annual exceedances at sites with sufficient data averaged over the sites.

e These data are derived from the Annual Housing Survey for owner occupied housing units, and report the percent reporting undesirable neighborhood conditions and percent reporting inadequate neighborhood services. They are for varying years -- 1977: Boston, Detroit, Dallas, Memphis, Washington, DC, Baltimore, Los Angeles, and Phoenix; 1976: New York, Housgon, Indianapolis, and Cleveland; 1975: Chicago, Philadelphia, San Diego, San Antonio, San Francisco, Milwaukee, and Columbus.

f These data are the FBI total violent crimes per 100 population for 1981 as reported in the Statistical Abstract of the U. S. and the County and City Data Book.

Table 2: A Comparison Across Several Studies of the Percentage Effects on Housing Prices of a One Standard Deviation Improvement in Each Amenity Variable

Study Author(s)	City	Tenure Type in Study	Amenity Measures: Physical Condition	School Quality	Crime	Racial Composition	Neighborhood Socioeconomic Status	Air Quality	Access to Work and Commerce	Noise	Overall Neighborhood Rating
Follain and Malpezzi	39 SMSAS	Owner	1.9%*	W	W	-	-	-	.4%	W	3.5%*
Follain and Malpezzi	39 SMSAS	Renter	1.2%*	W	W	-	-	-	W	W	2.0%*
Kain and Quigley	St. Louis	Owner	4.3%*	3.0%*	.8%	W	6.4%*		NR	-	-
Kain and Quigley	St. Louis	Renter	4.6%*	2.1%	W	W	2.0%	-	W	-	-
Barnett	Green Bay	Renter	2.6%*	NS	NS	NS	NS	-	3.0*	-	-
Noland	South Bend	Renter	1.5%*	NS	NS	NS	NS	-	4.8%*	-	-
Merrill	Pittsburgh	Renter	2.8%*	NS	NS	NS	0	-	.7%	-	-
Merrill	Phoenix	Renter	1.6%*	NS	NS	NS	0	-	1.7%*	-	-
Bartik	Pittsburgh	Renter	4.6%*	.3%	1.6%*	W	-	-	W	.5%	-
Bartik	Phoenix	Renter	1.2%	.1%	.6%	3.5%*	-	-	1.2%*	W	-
Li and Brown	Boston	Owner	9.4%*	1.7%	1.9%*	-	.8%	.5%	3.9%*	-	-
Mark and Parks	St. Louis	Owner	1.4%*	W	.1%	.7%	15.3%*	-	NS	-	-

Table 2: continued

Key: * indicates variable in statistically significant at 10% level

W means variable has "wrong" sign

NS means variable is insignificant and coefficient is not reported

NR means variable's coefficient is not reported and significant is unclear

- means variable in this category is not included in study

Note: 1. For purposes of this table, all the changes considered are improvements; that is, we consider changes that would be expected to positively affect housing prices, such as a one standard deviation decline in the crime rate.

2. All percentage effects are evaluated at the means of each study's data.

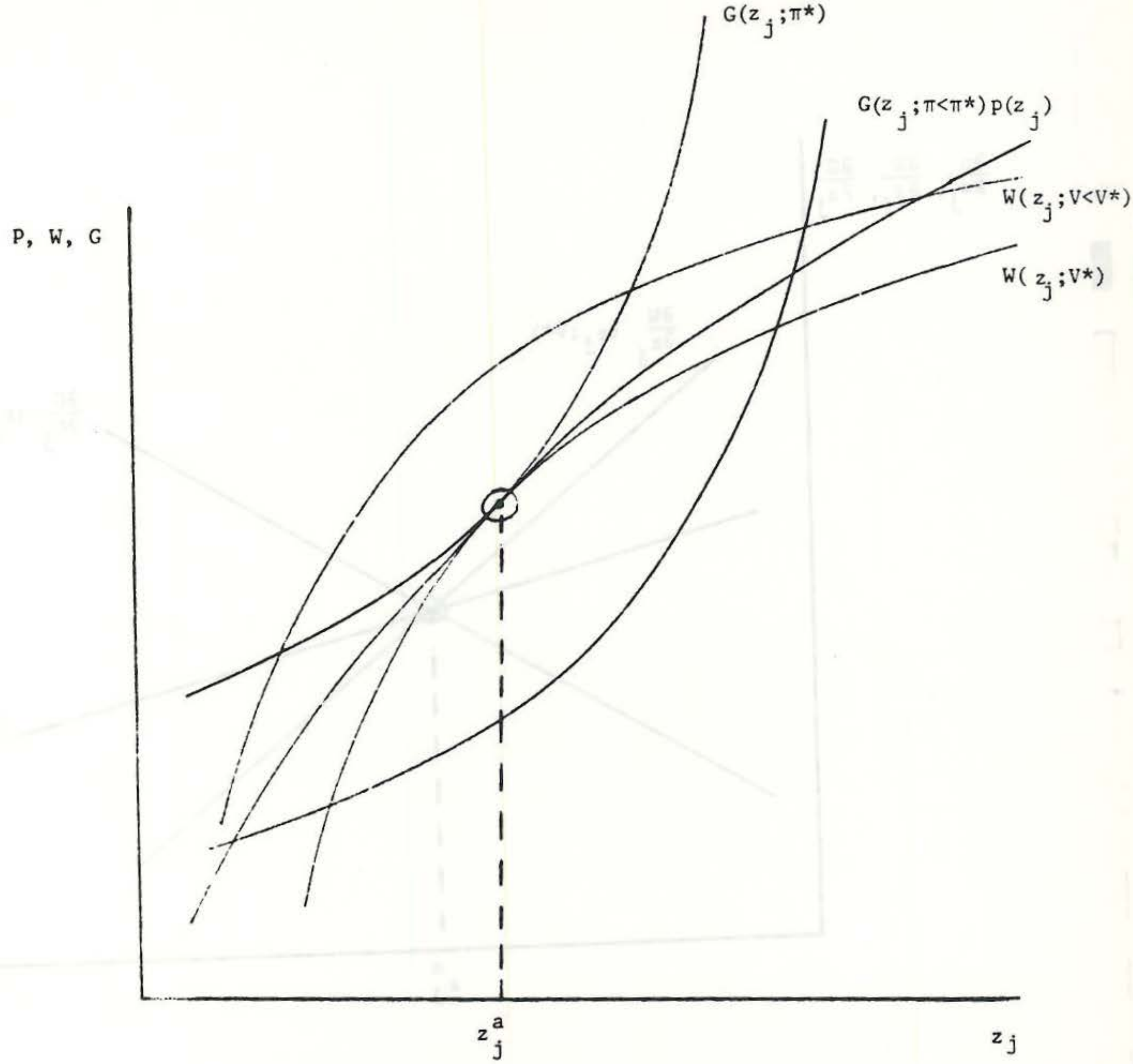

Figure 1

The Relationship Between Market Prices, Bid Prices, Offer Prices, and Characteristic z_j, Holding Other Characteristics Constant at Their Optimal Level

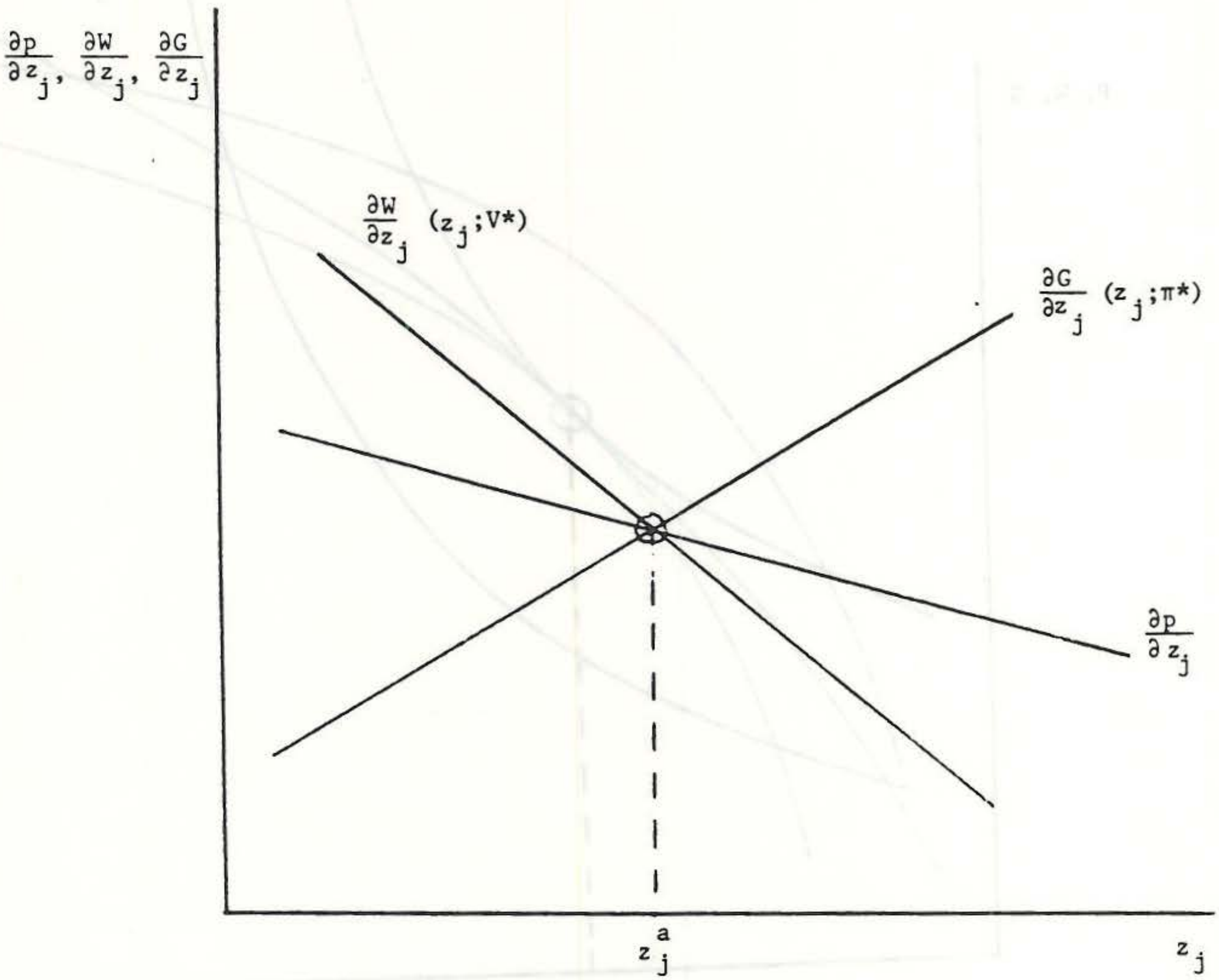

Figure 2

The Marginal Price, Marginal Bid, and Marginal Offer Curves
Corresponding to the Optimum in Figure 1

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HOUSEHOLD WILLINGNESS TO PAY FOR RISK REDUCTION IS ROUGHLY PROPORTIONAL TO THE MAGNITUDE OF RISK REDUCTION

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1. Introduction

Policymakers increasingly make decisions that affect the risks faced by households. For example, the Environmental Protection Agency determines how stringently to regulate the disposal of toxic wastes, the Occupational Safety and Health Administration determines standards for workplace safety, and the Consumer Products Safety Commission considers how safe products should be. Ideally, the stringency of these regulations should depend on the benefits to households of these risk reductions. This paper considers some implications of economic theory for how household willingness to pay for risk reduction will vary with the magnitude of the risk reduction.

More specifically, this paper analyzes household willingness to pay for risk reduction under the assumption that household's well-being is given by their expected utility over states of the world (the von Neumann/Morgenstern model). Using this assumption, I show that a household's marginal willingness to pay for risk reduction should be roughly constant over the variations in risk that we empirically observe. This implies that a household's total willingness to pay for risk reduction is roughly proportional to the magnitude of the risk reduction.

This theoretical result makes easier the task of empirically estimating household benefits from risk reduction. For example, this result facilitates the use of hedonic housing price models for estimating the benefits of risk reduction. Ordinarily, the variation of housing prices with risk only reveals the marginal benefits of risk reduction. In equilibrium, each household chooses a bundle of housing characteristics (including risk) such that the household marginal benefit from each characteristic is equal to the characteristic's marginal hedonic

price. The marginal prices thereby reveal marginal benefits. For most characteristics, however, the marginal benefit curve can have any shape; without some econometric procedure to estimate this marginal benefit curve (see Bartik 1983, Brown and Rosen 1981, Freeman 1979) it is impossible to infer the benefits for non-marginal improvements. But for the characteristic of risk, economic theory implies that the marginal benefit curve is approximately horizontal. We can, therefore, extrapolate from observed marginal prices and benefits to the case of non-marginal improvements.

Because the von Neumann/Morgenstern model has been challenged by numerous experiments (see Schoemaker 1982 for a review), it is also important to determine whether these results hold up in alternative models. I consider specifically the suggestion of Kahneman and Tversky (1979) that transformations of probabilities rather than actual probabilities enter the utility function. As a result of this change, household willingness to pay is no longer proportional to the size of the risk reduction. With plausible assumptions about the probability transformations, however, some predictions can be made about the willingness to pay for different risk reductions. Finally, I make suggestions about how survey evidence can be used to test the von Neumann/Morgenstern model vs. the Kahneman/Tversky model.

2. The von Neumann/Morgenstern Model and Household Willingness to Pay for Risk Reductions

2.1 The Model

Assume that there are two states of the world, the first in which no adverse event takes place (probability p), the second in which some adverse event occurs (probability [1-p]). Household utility in a given state of the world is defined over a vector of housing characteristics ($\underline{z}$), and expenditure on goods other than housing (x). (The separate inclusion of housing characteristics will allow us to analyze housing choices within the hedonic model.) Household utility in the first state is $U_1(\underline{z},x)$, in the second state $U_2(\underline{z},x)$, with $U_1 > U_2$ at the same $\underline{z},x$. Note that the utility function is state-dependent; this modification of the usual von Neumann/Morgenstern model has the important implication that the marginal utility of income ($\partial U_i/\partial x$) may vary over states of the world. Household preferences before it is known which state occurs are described by their expected utility over states of the world, or

$$(1) \qquad \bar{U} = pU_1(\underline{z},x) + (1-p)U_2(\underline{z},x).$$

Household's ex ante marginal willingness to pay for risk reduction (an increase in p) is their marginal rate of substitution of money (x) for p, or

$$(2) \qquad (\partial \bar{U}/\partial p)/(\partial \bar{U}/\partial x) = \frac{U_1 - U_2}{p\dfrac{\partial U_1}{\partial x} + (1-p)\dfrac{\partial U_2}{\partial x}}$$

This marginal willingness to pay for p will in general be a function $f_p(\underline{z},x)$ of $\underline{z}$ and x, or, because expected utility v is a monotonic function of x, marginal WTP is also a function $\underline{z}$ and v, $W_p(\underline{z},v)$.

Housing units are assumed to be described by the $\underline{z}$ bundle, and the safety p associated with that location. Without loss of generality, households can be assumed to be renters, because homeowners can be regarded as renters who rent from themselves. Market rents r will vary with $\underline{z}$ and p according to a hedonic rent function $r(\underline{z},p)$. In maximizing utility subject to the hedonic rent function, households will equate their marginal WTP for p to the marginal price of p in the hedonic, $\partial r/\partial p$.[2] Household marginal WTP is hence observable if one can estimate r( ), and the $\underline{z}$ and p chosen by a particular household is known. In the hedonic context, the marginal WTP is more commonly known as the marginal bid.

Consider the benefits of reductions in risk at various locations within a metropolitan area. If households do not move in response to this change, the efficiency benefits of this change are the sum of all households' WTP for the improvement at their location. In another paper (Bartik 1984), I show that this measure is in general an underestimate of true social benefits; intuitively, allowing household mobility can only add social benefits. Here, however, I focus on measuring household WTP for the improvement, if no mobility occurs. A compensating variation measure of an improvement in safety from p_0 to p_1 is given by

$$(3) \qquad W^{CV} = \int_{p_0}^{p_1} W_p(\underline{z},v_0,p)\,dp$$

where v_0 is the original level of utility. The equivalent variation measure of an improvement is

$$(4) \qquad W^{EV} = \int_{p^o}^{p_1} W_p(\underline{z},v_1,p)\,dp$$

where v_1 is the final level of utility. Knowledge of the hedonic tells us the household marginal WTP at the initial point of the CV measure

$[W_p(\underline{z},v_0,p_0)]$, but no other points are observed along the marginal WTP curves under which the CV and EV measures integrate.

This paper's main assertion is that W_p is approximately constant as p varies. Hence, CV or EV can be approximated by the product $(p_1-p_0)W_p(\underline{z},p,v_i)$ where p is some probability between p_0 and p_1, and v_i is the original or final utility level. In particular, CV can be approximated by the product $(p_1-p_0)W_p(\underline{z},p_0,v_0)$. This particular product can be empirically calculated because $W_p(\underline{z},p_0,v_0)$ is equal to the observed marginal price of p chosen by the household at the original safety level p_0. This result also implies that the household WTP for an improvement from p_2 to p_3 is approximately equal to $(p_3-p_2)/(p_1-p_0)$ times the WTP for an improvement from p_0 to p_1, that is WTP is proportional to the size of the improvement.

2.2A Proof that Marginal WTP Is Approximately Constant

Consider the equation (3) expression for CV. Applying a Taylor-series expansion to the marginal WTP function, we obtain

$$(5) \qquad W^{CV} = \int_{p_0}^{p_1} W_p(\underline{z},v_0,p)dp \doteq \int_{p_0}^{p_1} [W_p(\underline{z},v_0,p_0) + \frac{\partial W_p}{\partial p}(p-p_0)]dp$$

The partial derivative $\partial W_p/\partial p$ is evaluated at $(\underline{z},v_0,p_0)$. Integrating this expression leads to

$$(6) \qquad W^{CV} \doteq (p_1-p_0)W_p(\underline{z},v_0,p_0) + \tfrac{1}{2}[\frac{\partial W_p}{\partial p}][p_1-p_0]^2$$

Hence, CV is equal to the CV that would occur if marginal WTP were perfectly constant, plus another term. The goal now is to show that the second term is likely to be relatively small. This requires an evaluation of $\partial W_p/\partial p$.

To analyze the partial derivative of the marginal WTP, it is easier to consider the marginal WTP as a function of $\underline{z}$, x, and p than as a function of $\underline{z}$, v and p. It can be shown that the partial derivative of the compensated marginal WTP function is related to the partial derivatives of the uncompensated function in the following manner:

$$(7) \qquad \frac{\partial W_p}{\partial p} = \frac{\partial f_p}{\partial p} - \frac{\partial f_p}{\partial x} W_p.$$

Using equation (2) [marginal WTP = $(U_1-U_2)/(p \frac{\partial U_1}{\partial x} + (1-p) \frac{\partial U_2}{\partial x})$], the first term in equation 7 can be written as

$$(8) \qquad \frac{\partial f_p}{\partial p} = -W_p \frac{\frac{\partial U_1}{\partial x} - \frac{\partial U_2}{\partial x}}{p \frac{\partial U_1}{\partial x} + (1-p) \frac{\partial U_2}{\partial x}}$$

Substituting eq. 8 into eq. 7, and algebraically manipulating the second term, we obtain

$$(9) \qquad \frac{\partial W_p}{\partial_p} = -W_p \frac{\frac{\partial U_1}{\partial x} - \frac{\partial U_2}{\partial x}}{p \frac{\partial U_1}{\partial x} + (1-p) \frac{\partial U_2}{\partial x}} - (\frac{\partial f_p}{\partial x} \frac{x}{f_p})(\frac{W_p}{x})W_p$$

$$= -W_p M - E(W_p/x)W_p$$

where M is the percentage change in the weighted marginal utility of money as more weight is put on state 1, and E is the elasticity of marginal WTP with respect to x. In turn, substituting this equation into the eq. 6 approximation for CV, and simplifying yields

$$(10)\ W^{CV} = (p_1-p_0)W_p(\underline{z},r_0,p_0) + \tfrac{1}{2}(p_1-p_0)^2[-W_pM - E(\frac{W_p}{x})W_p]$$

$$= (p_1-p_0)W_p(\underline{z},v_0,p_0)\{1 - \tfrac{1}{2}(p_1-p_0)(M + E\frac{W_p}{x})\}$$

Hence, CV is equal to the CV if Marginal WTP were constant times one minus an adjustment term that depends on: (1) the size of the change in probability considered (p_1-p_0); (2) the percentage change in the weighted marginal utility of money as more weight is put on state one (M); (3) the elasticity of marginal WTP with respect to x(E); (4) the ratio of the household's marginal WTP to its money $(\frac{W_p}{x})$. The last two terms reflect the need to take away x as p increases to keep utility constant, and the consequent effect on household marginal WTP.

From this analysis, if the marginal utility of money were constant across states, and there were no "income effects" on marginal WTP, the adjustment term would be zero and marginal WTP would be constant. A non-zero income effect on marginal WTP will have a negative effect on household WTP; as p increases, the household's income is reduced to keep utility constant, thus increasing the marginal utility of income and reducing marginal WTP. Variations in marginal utility of income across states of the world have an uncertain effect on WTP. If the marginal utility of income is greater in state 1, the desired state, the increase in probability of state 1 increases the marginal utility of income and reduces household marginal WTP. If the marginal utility of income is greater in state 2, household marginal WTP will increase as the probability of state 1 increases.

What are plausible values for the components of Eq. 10's adjustment term? The elasticity of the marginal WTP with respect to money (E) would be expected to be in the range from $\frac{1}{2}$ to 2. There is little direct evidence on this, but some insight can be gained from ordinary demand concepts. For example, if the price elasticity of demand for risk reduction were about (-1), a marginal WTP money elasticity of 2 would imply an income elasticity of about 2. For a fixed price, doubling income would quadruple the marginal valuation; a fourfold increase in quantity would be needed to re-equate the marginal valuation to the fixed price.

Second, the ratio of marginal WTP to income might be also expected to be in the range from one to two. The marginal WTP indicates the money the household would be willing to pay for a small risk reduction, but measured as a money rate per unit of risk reduction. The risk reduction units are the actual probabilities, so one unit of risk reduction is a change in p from zero to one. A change in p from zero to one might be valued by a household at its entire income x. For smaller changes in p, one would expect a risk-averse household to be willing to pay a money rate per risk reduction until that is higher than the WTP for the complete change from p=0 to p=1.

Finally, it is difficult to have much intuition as to how the marginal utility of income will vary over states of the world. In general, however, it seems unlikely that the change in marginal utility of income as probability increases will make much difference. Consider, for example, an increase in the marginal utility of income in state

1. As this increase approaches infinity, the limit of the M term approaches $(1/p_0)$. Assuming p_0 is greater than .75, this term can be no greater than 1.33. As we will see, when multiplied by $(-\frac{1}{2})$ and (p_1-p_0) in equation (10), this term will only require a 13.3% downwards adjustment in WTP for a (p_1-p_0) change of .10. A very high marginal utility of state 2 income could cause greater problems. Increasing this marginal utility to infinity yields a limit to this component of $(\frac{-1}{1-p_0})$, which will equal (-4) if $p_0 = .75$. This would yield a 52% upwards adjustment in WTP for a .10 increase in p. This upwards adjustment to some extent, however, merely counteracts the downwards adjustment of the second component $[E(W_p/x)]$ of the adjustment term. So, for a considerable range of increase in $\partial U_2/\partial x$, the net effect of the adjustment term will be small. In the following, I assume $\frac{\partial U_1}{\partial x} = s \frac{\partial U_2}{\partial x}$, with s between 0.5 and 2.0.

Table 1 uses a range of values for all these parameters to determine the bias in simply assuming the marginal WTP is constant. The terms reported in the table represent the percentage by which the constant marginal WTP calculation is greater than the true WTP. From this table, it is clear that under a reasonable variety of assumptions, the bias will usually be in the 10 to 20% range. Larger bias figures only occur if one examines very large improvements in safety (20% or more) and assume that W_p is large in relation to x $(W_p/x = 2.0)$ and that W_p is very elastic with respect to x(E = 2.0).

The numbers in table 1 represent the bias in extrapolating from the marginal WTP at one point, which one might want to do using estimated hedonic marginal prices. It is also possible to calculate how one would expect household's stated WTP for risk reduction to vary from

Table 1: Percentage Bias in Calculating WTP Caused by Assuming Constant Marginal WTP

		Increase from p=.8 to p=.9		Increase from p=.8 to p=1.0	
		s = .5			
		W_p/x		W_p/x	
		1.0	2.0	1.0	2.0
	.5	-2%	+1%	-3%	+2%
E	1.0	+1%	+6%	+2	12
	2.0	+6%	+16	+12	32
		s = 1.0			
		W_p/x		W_p/x	
		1.0	2.0	1.0	2.0
	.5	+3%	+5%	+5%	+10%
E	1.0	5	10	10	20
	2.0	10	20	20	40
		s = 2.0			
		W_p/x		W_p/x	
		1.0	2.0	1.0	2.0
	.5	+5%	+8%	+11%	+16%
E	1.0	8	13	16	26
	2.0	13	23	26	46

Note: Table reports $(100)(\frac{1}{2})\Delta P\{[\frac{s-1}{P_0 s + 1 - p_0}] + [E][\frac{W_p}{x}]\}$. The resulting number is the bias in using a constant marginal WTP assumption to calculate WTP for a change in p, computed as a percentage of the constant marginal WTP calculation. A positive number in the table means a positive bias in the calculation; i.e., the constant marginal WTP calculation is greater than true WTP by that percentage. The table shows how the bias varies with s, E, and W_p/x.

strict proportionality to the size of the risk reduction. These theoretical predictions could then be compared with actual survey evidence to test the theory. Table 2 reports the percentage difference between twice the true WTP for a safety improvement from p=.8 to p=.9, and the true WTP for a safety improvement from p=.8 to p=1.0. The figures in the table are the percentage by which the WTP for the larger improvement is less than twice the WTP for the smaller improvement, calculated as a percentage of twice the WTP for the smaller improvement. The table indicates that the WTP for larger improvements is generally only 5-15% less than the prediction from simply proportionally inflating the WTP for the smaller improvement. These figures are generally less than in table 1 because household WTP for the smaller improvement already incorporates the downwards slope of the marginal WTP function as p increases. Survey evidence on household's valuations of changes in risk could test the predictions in table 2, particularly if w_p/x and E would be ascertained.

The final implication of these restrictions on the shape of the marginal WTP function are restrictions on the shape of the hedonic price function. At any household's chosen equilibrium, the household compensated marginal WTP for risk reduction must have a more negative slope than the marginal price function for risk reduction, or

$$(11) \qquad \frac{\partial^2 r}{\partial p^2} > \frac{\partial w_p}{\partial p} .$$

This is a second-order condition for utility maximization in this problem (see Rosen 1974 or Bartik 1982). Substituting equation (9) (the deriva-

Table 2. Percentage Difference Between WTP for Improvement from p=0.8 to p=1.0 and Twice WTP for Improvement from p=0.8 to p=0.9

		s = .5		s = 1.0		s = 2.0	
		W_p/x=1.0	W_p/x=2.0	W_p/x=1.0	W_p/x=2.0	$W_p.x$=1.0	W_p/x=2.0
	.5	+1%	-1%	-2%	-5%	-6%	-9%
E	1.0	-1%	-6%	-5%	-11%	-9%	-15%
	2.0	-6%	-19%	-11%	-25%	-15%	-30%

Note: Calculated as $\frac{\text{WTP(0.8 to 1.0) - 2[WTP(0.8 to 0.9)]}}{\text{2[WTP(0.8 to 0.9)]}}$

tive in terms of the uncompensated marginal WTP function) into (11), one obtains

$$(12) \qquad \frac{\partial^2 r}{\partial p^2} > -W_p M - W_p E[\frac{W_p}{x}]$$

Dividing both sides by $W_p (= \frac{\partial r}{\partial p}$ at the equilibrium) and assuming $\frac{\partial U_1}{\partial x} = s \frac{\partial U_2}{\partial x}$, results in

$$(13) \qquad \frac{\partial^2 r}{\partial p^2} / \frac{\partial r}{\partial p} \geq [\frac{1-s}{ps + 1-p}] - E\,(\frac{W_p}{x})$$

The left-hand side is interpretable as the percentage change in the marginal price of p for a one percent increase in p. The percentage change must be greater than a number that depends on p, s, E, and W_p/x. Table 3 compiles valus of this lower bound for various values of these parameters.

From table 3, a one percent increase in p can either increase the hedonic marginal price of p, leave it unchanged, or reduce the marginal price by less than three or four percent in absolute magnitude. In other words, the hedonic rent function can be convex with respect to p, or a straight line, but the function should not be "too concave" anywhere with respect to p. This is a significant restriction on the shape of the hedonic. This prediction can potentially be empirically tested. For example, if empirical hedonic rent functions, estimated using a flexible functional form, indicated that a 10% increase in p led to a reduction in the hedonic marginal price of more than 50%, this would contradict the theory outlined here.

Table 3. Lower Bound for Percentage Change in Hedonic Marginal Price of Risk Reduction for One-Percent Increase in Probability of No Loss, Starting at p=.8

	s = .5		s = 1.0		s = 2.0	
	W_p/x=1.0	W_p/x=2.0	W_p/x=1.0	W_p/x=2.0	W_p/x=1.0	W_p/x=2.0
.5	.3	-.2	-.5	-1.0	-1.1	-1.6
E 1.0	-.2	-1.2	-1.0	-2.0	-1.6	-2.6
2.0	-1.2	-3.2	-2.0	-4.0	-2.6	-4.6

Note: Table reports $(\frac{1 - s}{ps + 1-p}) - E \frac{W_p}{x}$. This is equal to negative of numbers in Table 1, times 2, divided by (100)Δp.

3. The Kanneman/Tversky Model and Household Willingness to Pay for Risk Reduction

3.1 Implications of the Kahneman/Tversky Model for WTP for Risk Reduction

Kahneman and Tversky have developed an alternative to the von Neumann/Morgenstern model for analyzing decision making under risk. This model is intended to explain numerous experimental results that apparently contradict standard expected utility theory (see Schoemaker 1982 or Kahneman and Tversky 1979 for a review). I will not try to analyze the effects on WTP for risk reduction of all of the features of the Kahneman-Tversky model. Instead, I focus on one particular feature of the Kahneman-Tversky model, its assumption that transformations of probabilities rather than actual probabilities enter the utility function.

Kahneman and Tversky argue that individuals tend to ignore extremely small probability events and overweight slightly larger but still small probabilities. Furthermore, they argue that in some medium range, from perhaps p=.05 to p=.95, that the weight placed on events varies less than proportionally with probabilities. All of these assertions can be explained if individuals use some function of probabilities rather than actual probabilities in assessing risk. This function would be zero for small probabilities, jump to some value greater than the probability for larger probabilities, and then have a slope less than one as the probability increased. In the present model, it is the probability of loss (1-p) that will usually be small. Kahneman and Tversky's model implies that a function G(1-p) rather than (1-p) will be used in assessing loss. This function is illustrated in Figure

1, which is closely patterned after Figure 4 in Kahneman-Tversky (1979, p. 283).

In general, there is no reason in the Kahneman-Tversky model to assume that the transformed probabilities [G(p) and G(1-p)] sum to one. However, Kahneman and Tversky also argue that individuals often maximize utility by dividing their choice set into a certain component, and a risky gain or loss multiplied by the transformed probability of that risk. In the present model, this implies that household preferences may be described by

$$(14)\qquad \begin{aligned} U &= U_1(\underline{z},x) + G(1-p)[U_2(\underline{z},x) - U_1(\underline{z},x)] \\ &= [1 - G(1-p)]U_1(\underline{z},x) + G(1-p)[U_2(\underline{z},x)] \end{aligned}$$

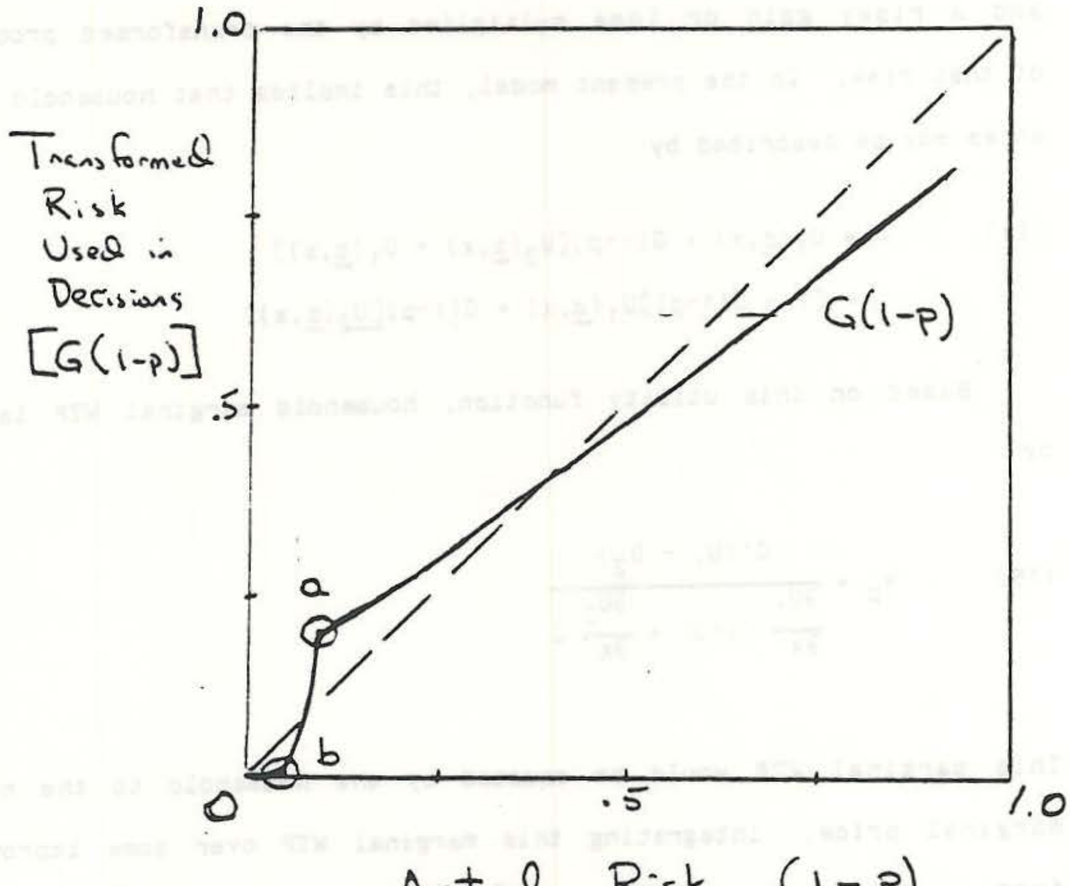
Based on this utility function, household marginal WTP is given by

$$(15)\qquad W_p = \frac{G'(U_1 - U_2)}{\frac{\partial U_1}{\partial x}(1-G) + \frac{\partial U_2}{\partial x} G}$$

This marginal WTP would be equated by the household to the hedonic marginal price. Integrating this marginal WTP over some improvement from p_0 to p_1, and again using the Taylor-series expansion, yields an approximation to household WTP for the improvement.

$$(16)\qquad \begin{aligned} W &= \int_{p_0}^{p_1} W_p dp \\ &= (p_1-p_0)W_p(\underline{z},v_0,p_0)\{1 - \tfrac{1}{2}[p_1-p_0][\frac{G''}{G'} + M_g + E\frac{W_p}{x}]\} \end{aligned}$$

Figure 1: Functional Relationship Between Actual Risk and Transformed Risk Used in Decisions, as Assumed by Kahneman/Tversky



where G' and G" are first and second derivatives, and $M_g = G'[(\partial U_1/\partial x) - (\partial U_2/\partial x)]/[(1-G)(\partial U_1/\partial x) + G(\partial U_2/\partial x)]$. Again, WTP equals the amount it would be if marginal WTP were constant, times one minus a correction term. This is a generalization of the earlier model. The earlier model (eq. 10) can be viewed as equation 16 with the assumption that $G = 1-p$, $G' = 1$, $G'' = 0$.

The most important change in this more general expression is the term (G"/G'). If some constant value of this term could be assumed as p varies, the probable numerical value of the bias in assuming constant marginal WTP could be calculated. If the G function is shaped as Kahneman and Tversky assume, however, G"/G' will be far from constant. In this case, a Taylor-series approximation is likely to be quite inaccurate. Equation (16), however, can be made exact by evaluating all derivatives at some p between p_0 and p_1. Hence, this equation implies that the G"/G' term has some potential for adding additional bias if G" is non-zero and large at some p between p_0 and p_1. In particular, if G" is positive, the constant marginal WTP assumption can lead to an overestimate of the true WTP, while if G" is negative, true WTP may be underestimated. These possibilities can be illustrated using Figure 1. Suppose the marginal WTP is known for some p to the right of point a. If we try to use that marginal WTP to predict the WTP for an improvement to the left of a, between a and b, we are likely to significantly underpredict the true WTP. Algebraically, this occurs because G" is negative near a. Intuitively, this occurs because marginal WTP increases greatly as we move to the left of a; a given improvement in actual safety results in the region a to b in a much larger improvement in perceived safety (i.e., $G' > 1$). Similarly, if we use the marginal WTP in the region from a to b to predict the WTP for an improvement to a point to the left of b, we will probably overpredict true WTP. Algebraically, G" is positive near b. Intuitively, the marginal WTP drops to zero to the left of b, because G' = 0.

To provide a numerical illustration of the possible biases in assuming constant marginal WTP, I will make a number of simplifying assumptions. Suppose increases in risk are ignored in the zero to one percent range; that the perceived risk is 10 percent when the actual risk is 5 percent, and that perceived risk equals actual risk when the actual risk is 20 percent. Suppose furthermore that the marginal utility of money is constant over states of the world and there are no income effects on marginal WTP. This implies that the only factor preventing marginal WTP from being constant is the transformation function G. Under these assumptions, true WTP for an improvement in safety from p_0 to p_1 will be given by

$$(17) \quad W^{CV} = \int_{p_0}^{p_1} W_p dp = \int_{p_0}^{p_1} \frac{G'(U_1 - U_2)}{\frac{\partial U_1}{\partial x}(1-G) + \frac{\partial U_2}{\partial x} G} dp$$

$$= \frac{U_1 - U_2}{\frac{\partial U}{\partial x}} \int_{p_0}^{p_1} G' dp$$

$$= k[G(1-p_0) - G(1-p_1)]$$

From Eq. (17), true WTP will not be proportional to the size of the risk reduction unless $G(r_1) - G(p_0)$ is proportional to $(p_1 - p_0)$, which will not be the case because G' is not constant. Using the specific numbers given above, the true WTP can be written in terms of k as

(18) (a) $W^{CV}(p_0 = .8 \text{ to } p_1 = .95) = k[.20 - .10] = .10k$

(b) $W^{CV}(p_1 = .95 \text{ to } p_2 = .99) = k[.10 - 0] = .10k$

(c) $W^{CV}(p_2 = .99 \text{ to } p_3 = 1.0) \;]\; k[0 - 0] = 0$

In this example, an improvement in safety from .95 to .99 (reduction in risk from 5 to 1 percent) is valued by the same amount as an improvement in safety from .8 to .95 (reduction in risk from 20 percent to 5 percent) even though the improvement from .95 to .99 is only about one-fourth the magnitude of the latter improvement. Furthermore, improvements in safety beyond .99 are not valued at all.

The Kahneman-Tversky model thus implies that in general, the assumption of a constant marginal WTP will be inappropriate. Given the shape of the transformation function assumed by Kahneman and Tversky, however, information about households' marginal WTP, obtained from hedonic price studies or elsewhere, may still be useful. For example, if figure 1 is correct and the transformation function has approximately constant slope to the right of point a, then the marginal WTP will be approximately constant in this range. Furthermore, projecting a constant marginal WTP to the left of a is likely to lead to an underestimate of true WTP. Thus, one can use marginal WTP values calculated from hedonic price functions to: (1) approximate actual benefits up to some critical level of risk, a; (2) provide a lower bound for the benefits from further reductions in risk.

3.2 Testing and Using the Kahneman/Tversky Model

Using survey data, it should be possible to evaluate which model, Kahneman/Tversky or von Neumann/Morgenstern, better explains individual's behavior towards risk. As developed in section 2, the von Neumann/

Morgenstern model predicts that household WTP for risk reduction should be proportional to the magnitude of the risk reduction. In contrast, if household preferences follow the Kahneman/Tversky model, survey responses would be expected to be quite different. As risk is reduced, WTP would at first be roughly proportional to the magnitude of the risk reduction. But at some critical point (a in figure 1), WTP per a given change in p should increase enormously. Finally, at some level of safety quite close to 1 (point b in fig. 1), households WTP for further risk reduction would decline to near zero.

If households follow the Kahneman/Tversky model, it would be quite important to determine these critical points "a" and "b" for different types of households. As discussed above, these critical points determine the range in which the use of marginal WTP values from hedonic price studies result in an underestimate of true WTP. Furthermore, one would expect that point b would often be the efficient level of risk reduction. To take an extreme example, suppose that the marginal cost of risk reduction is constant (per given increase in p). Then if any risk reduction at all is efficient, point b would be optimal, because marginal WTP increases as we move from the right to point b. This result does not hold if the marginal cost of risk reduction increases as more and more risk is eliminated. However, if the marginal cost of risk reduction does not increase too rapidly, then point b will still in many cases be the optimal level of risk reduction.

4. Conclusion

The most important conclusion of this paper is that household WTP for risk reduction is likely to be roughly proportional to the magnitude of the risk reduction. This proportionality only fails as prices, but this certainly does not imply that there are no benefits from reducing the risk.

FOOTNOTES

[1]I would like to thank Kerry Smith for helpful conversations on this subject. Portions of this research were supported by the Environmental Protection Agency.

[2]This is pointed out in Smith (1984).

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MEASURING THE BENEFITS OF AMENITY IMPROVEMENTS IN HEDONIC PRICE MODELS[1]

Timothy J. Bartik

1. INTRODUCTION

Empirical measurement of the benefits of improvements in public goods is increasingly important for policy. For example, evaluating the benefits of environmental goods is crucial in determining the stringency of environmental regulations. The benefits of these public good improvements is usually assumed to be the sum of all households' willingness to pay for the improvements, in the spirit of the original Samuelson public good model.

One empirical model often used to measure the value consumers place on public goods is the hedonic housing price model (Rosen 1974). To use this model, the level of the public good must vary from house to house within a housing market. Public goods that vary spatially are often called amenities (Diamond and Tolley [1982], Bartik and Smith [1985] review the amenities literature.)

Housing prices will vary with amenities according to a hedonic price function. Housing price variations and consumer choices can be used to estimate a household's marginal willingness to pay or marginal bid function for the amenity, although the appropriate econometric procedure is in some dispute (Bartik [1983], Brown and Rosen [1982], and Diamond and Smith [1982] discuss the econometric issues). Using these estimates, the usual procedure for calculating benefits is to integrate under the marginal bid function of the household at each location between the before and after levels of the amenity at each location, and then sum over all households, (for example, Harrison and Rubinfeld [1978].) This will approximate the sum of all households' willingness to pay for the amenity improvements at their original location.

The first purpose of this paper is to point out that in a hedonic model, the benefits of amenity improvements will not be given by this sum of all households' valuations. This benefit measure overlooks the spatial rearrangement of households and housing supply adjustments of property owners that follow amenity improvements. Unfortunately, a conceptually accurate benefit measure is not practical, because we would have to solve for the new equilibrium hedonic function in order to ascertain the spatial rearrangement and housing stock adjustments that will occur. Explicit solutions for hedonic price functions are at present usually unobtainable.

The second purpose of this paper is to suggest practical procedures that might be used to estimate the benefits of amenity improvements. Two benefit measures are proposed that bound true benefits. The household's valuation of the amenity change at its current location, (the usual measure) is shown to always be an underestimate of the true benefits. An overestimate of true benefits is provided by the hypothetical increase in property values that would occur due to amenity improvements if the hedonic price function remained unchanged. The paper also shows the special circumstances under which these measures will be exact rather than an under or overestimate. Finally, the paper discusses the feasibility of approximating the benefits if only the hedonic price function is known, while the marginal bid function cannot be estimated. This situation arises frequently in empirical work because of the many econometric assumptions needed to estimate marginal bid functions.

2. HOUSEHOLDS' VALUATIONS OF THE AMENITY IMPROVEMENTS AT THEIR ORIGINAL LOCATION IS AN INACCURATE BENEFIT MEASURE BECAUSE IT OVERLOOKS ADJUSTMENTS BY HOUSEHOLDS AND LANDLORDS

2.1 A Proof

A proof of the inaccuracy of the usual benefit measure (households' valuations of the improvements at their original location) can be obtained by deriving the true benefit measure, and comparing it with the usual measure. Consider a set of improvements in amenities of various amounts at different locations within a city. In general, this set of improvements will lead to a change in the hedonic price function. Faced with a new hedonic function, and a different level of amenities at their original location, most households will choose a new level of amenities and a new location. In addition, property owners may choose different levels of housing characteristics. To simplify the exposition, I assume that all households rent housing from landlords; this assumption does not limit the generality of the analysis because homeowners can be treated as renters who rent from themselves. The total social benefits of the amenity improvements are then equal to the sum of all households' gross willingness to pay for their new location minus the change in rent they pay, plus the change in profits of landlords.

Under these assumptions, the net benefits to household i (BH_i) of the improvements can be written as:

$$(1) \qquad BH_i = [E(A^a_{ni}, Z^a_{ni}, v_i) - E(A^b_{oi}, Z^b_{oi}, v_i)]$$

$$- [p^a(A^a_{ni}, Z^a_{ni}) - p^b(A^b_{oi}, Z^b_{oi})]$$

Equation (1) uses the following notation: E( ) is the household's bid function, that is the rent it must pay for a given housing unit to give it a particular utility level;[2] A is the vector of amenities at a particular location; Z is a vector of other housing quantities, and v_i is some utility level for household i. The subscripts "ni" and "oi" on the A and Z variables indicate the level of A or Z for household i at its new and old locations respectively. The superscripts "a" and "b" on A and Z indicate the level of amenities and housing characteristics at a location after and before the amenity improvement and consequent housing stock adjustments. $p^a(\ )$ and $p^b(\ )$ are the equilibrium hedonic price functions after and before the amenity improvements, respectively.

The expression in equation (1) can be equal to either the compensating variation or equivalent variation measure of the benefits to the household, depending on the level of utility v_i. If v_i is the household's original level of utility, then equation (1) gives a compensating variation measure of benefits. In this case, the first expression in brackets $[E(A^a_{ni}, Z^a_{ni}, v_i) - E(A^b_{oi}, Z^b_{oi}, v_i)]$ shows how much more the household is willing to pay for (A^a_{ni}, Z^a_{ni}) than for (A^b_{oi}, Z^b_{oi}) at its original utility level; that is, the amount of money that if taken away from the household at its new consumption levels of A and Z would give it the utility it originally had. The second expression in brackets $[p^a(A^a_{ni}, Z^a_{ni}) - p^b(A^b_{oi}, Z^b_{oi})]$ gives the extra rent the household actually has to pay. Hence the entire expression in (1) shows the extra amount, above the change in rents, that would have to be taken away from the household consuming A^a_{ni} and Z^a_{ni}, and paying rent $p^a(A^a_{ni}, Z^a_{ni})$, to keep the household at its original utility level. This is precisely the definition of a compensating variation measure.

Similar reasoning can show that equation (1) is an equivalent variation measure of the household's benefits if v_i is the household's final level of utility.

Landlord's profits change after the amenity improvement for four reasons. First, amenity improvements may affect landlord costs (e.g., lower crime may reduce vandalism of property). Second, the change in amenities at the site they own changes the rents received even if the overall hedonic price function remains unchanged. Third, the shift in the hedonic price function also affects rent received by landlords. Finally, landlords may respond to these changes by choosing a different profit-maximizing mix of housing characteristics. Taking all four factors together, the resulting change in landlord j's profits (BL_j) is given by

$$(2) \qquad BL_j = [p^a(A_j^a, Z_j^a) - C(A_j^a, Z_j^a)]$$
$$- [p^b(A_j^b, Z_j^b) - C(A_j^b, Z_j^b)]$$

The notation in equation (2) is similar to that in equation (1), but only a j subscript is needed because landlords do not change locations. C( ) is the landlord's cost function.

As usual for public goods, total social benefits (TSB) of the amenity improvement are the sum of benefits to all those affected by the public good, in this case households and landlords, or

$$(3) \qquad TSB = \sum_i BH_i + \sum_j BL_j$$

The usual benefit measure is quite different from that derived above. The usual measure is the sum over all households of the household's gross willingness to pay for the amenity change at its original location. For household i, this benefit measure (BM_{1i}) is

$$(4) \qquad BM_{1i} = E(A^a_{oi}, Z^b_{oi}, v_i) - E(A^b_{oi}, Z^b_{oi}, v_i)$$

The usual social benefit measure is this individual measure summed over all i, or

$$(5) \qquad BM_1 = \sum_i BM_{1i}$$

In general, there is no reason for the benefit measure in equation 5 (BM_1) to be the same as the true social benefit measure (TSB) in equation 3. Only under very restrictive assumptions will the two measures be the same. More specifically, the usual measure will be the same as the true measure if: (1) no household changes locations; (2) amenity changes do not affect landlord costs; and (3) no landlord's housing supply choices change as a result of the amenity improvements and hedonic function shifts.

If all three of these assumptions hold, equations (1) and (2) can be reduced to equation (4) by matching up each household with his landlord. The landlord costs in equation (3) then net out, the rent changes in equations (1) and (2) cancel out as a pecuniary transfer between tenant and landlord, and we are left with equation (4) as an expression of the true social benefits associated with a particular household-landlord pair. However, all these algebraic manipulations depend on the unrealistic assumptions that households do not move and landlords do not adjust housing supply in response to amenity improvements, as well as the perhaps more realistic assumption that the amenity does not directly affect landlord costs.

2.2 Calculation of the True Benefit Measure is Infeasible Because it Requires a Solution to the Determinants of the Hedonic Price Function.

The problem with the correct social benefit measure described in (3) is that it is almost impossible to calculate. In particular, to derive this measure one would have to determine how the equilibrium hedonic price function is affected by the amenity improvements.

The requirements for an equilibrium hedonic price function are conceptually easy to describe. For each household i, the vector of housing characteristics and amenities demanded will be a functional of the hedonic price function, household income, and other observed and unobserved demand shifters, or

$$(6) \qquad (A_i, Z_i) = f[p(Z, A), y_i, DS_i]$$

where y_i is household i's income, and DS_i is a vector of observed and unobserved demand shifters. Similarly, for each landlord j the vector of housing characteristics supplied will be a functional of the hedonic price function, the vector of amenities at the landlord's location, and observed and unobserved supply shifters SS_j,

$$(7) \qquad Z_j = g[p(Z, A_j), A_j, SS_j]$$

The equilibrium hedonic price function will be the function that results in an exact match between housing bundles (Z, A) demanded and bundles supplied. In general the equilibrium hedonic function will depend on the distribution of household characteristics, landlord characteristics, and amenities in the housing market.

This problem of finding the equilibrium hedonic price function is not susceptible to analytic solution. The problem might be solvable by general equilibrium simulation methods, particularly if the problem was made discrete by assuming a limited number of housing types. However, I am unaware of any successful applications of this approach to the hedonic problem. Furthermore, any simulation solution will require a great deal of information that may not be available in many cases in which benefit measures are desired.

3. TWO ALTERNATIVE MEASURES THAT BOUND THE TRUE BENEFIT MEASURE

3.1 The Usual Benefit Measure is Always an Underestimate of the True Benefit Measure

Although the true measure may be unpractical, we can develop calculable measures that bound the true benefits. I show in this subsection that the usual benefit measure, the sum of all household valuations of the amenity changes at their original location, will generally be an underestimate of true benefits. The next subsection derives a measure that is generally an overestimate of true benefits.

The usual measure can be shown to be an underestimate of benefits by considering the effects of the amenity improvements in three hypothetical stages. These stages are not meant to correspond to any actual sequence of events in the real world. Rather, these three stages are a convenient analytic device for decomposing the benefits of amenity improvements.

In the first stage, we imagine that the amenity improvements take place at various locations within the housing market, but that no rents change, households do not move, and landlords do not adjust the housing stock. At the second stage, we allow rents at all locations to change to the level they will have under the new hedonic price function. Finally, at the third stage, households adjust by moving to their new equilibrium location, and landlords adjust by changing their desired housing stock. All three stages taken together include all the changes that occur because of the amenity improvements. Table 1 gives explicit algebraic formulas for the benefits to households and landlords at each stage.

The benefits of stage one, in which amenities change but no rent changes or adjustment take place, are equal to household valuations of the improvements in amenities at their current location, plus any cost savings of landlords due to amenity improvements. The efficiency benefits of stage 2 are zero because the rent change is a pecuniary transfer between landlords and tenants. At the third stage, both households and landlords must gain benefits by moving to their new equilibrium position, because by definition this equilibrium must yield the maximum possible utility and profits, respectively.

Summing these benefits from all three stages gives the total social benefits from the amenity improvements. From the above discussion, these social benefits must equal households' valuations of the improvements in amenities at their current location, plus any cost savings accruing to landlords, plus gains from adjustment by households and landlords. It seems reasonable to assume that amenity improvements usually do not increase landlord costs. As discussed above, by definition the benefits from household and landlord adjustment must be non-negative. Hence, total social benefits are equal to the sum of household valuations of the amenity improvements at their original location plus two non-negative numbers. Hence household valuation of the improvements at their original location must be an underestimate of the true social benefits.

This decomposition of total social benefits also demonstrates again, as asserted in section 2, that the usual measure of social benefits will be identical to the true measure if the amenity improvements do not yield landlord cost savings, and no household or landlord adjustment takes place. In this case, the two non-negative numbers mentioned above happen to be zero.

It seems worthwhile to explore in more detail the conditions under which the usual household valuation measure is an exact measure, and in particular, how likely these conditions are to hold in the real world. Considering landlord costs first, for many amenities one would think it plausible that there are no significant effects on landlord costs. For example, the cleanliness of the air is not likely to have any significant effect on landlord costs in providing different sized dwelling units.

Second, consider what circumstances could make it likely that households would not adjust location in response to amenity improvements throughout a housing market. This might occur if households were reluctant to move because of high financial or psychological moving costs. Households will also remain at the same location if the amenity improvements do not change the ordering of locations by amenity quality; and households always arrange themselves in the same order of amenity consumption, for example, if amenity consumption and household income always have a monotonic functional relationship. While these assumptions might seem plausible, further consideration reveals that these assumptions are unlikely to hold. For example, in general any policy that improves clean air in a metropolitan area will rearrange the ordering of locations by air quality. Furthermore, even if locations retain the same ordering by amenity quality, households are unlikely to retain the same ordering by amenity consumption. This occurs because household demand is for the whole housing bundle, and improvements in the amenity quality of a number of bundles, even if the same improvement takes place for all bundles, may change the relative attractiveness of different bundles. For example, suppose that there are only two households and two housing bundles. Furthermore, assume that one household is of high income, while the other household is low income, but that otherwise the households are identical. Finally, assume that initially housing unit A is of high construction quality but has low air quality, while housing unit B is of medium construction quality but has high air quality. The two households, given identical tastes, both agree that unit B is worth more than unit A.

Under these assumptions, one would expect the higher income household to obtain the higher quality unit (in this case, unit B) because it would be willing to bid more than the lower income household for the same quality increment. Now suppose some environmental policy improves the air quality at both sites by the same amount. Under these assumptions, unit A may now be considered by both households to be of greater overall quality. As before, the higher income household would be expected to outbid the lower income household for the higher quality unit, which is now unit A. This example shows that even a policy which raises amenity quality uniformly everywhere can affect households' location decisions.

Finally, consider the conditions under which landlords' housing production choices will remain unchanged. In general, landlords will choose a level of the vector Z such that $\frac{\partial p}{\partial z}(Z, A) = \frac{\partial C}{\partial z}(Z, A)$ or the marginal price of each Z equals its marginal cost. Their choice of Z will remain unchanged after the amenity improvements if the same Z_j^* satisfies this marginal condition, or

$$(8) \quad (a) \quad \frac{\partial p^b}{\partial Z}(A_j^b, Z_j^*) = \frac{\partial C}{\partial Z}(A_j^b, Z_j^*)$$

and

$$(b) \quad \frac{\partial p^a}{\partial Z}(A_j^a, Z_j^*) = \frac{\partial C}{\partial Z}(A_j^a, Z_j^*)$$

As can be seen from these equations, the marginal prices and cost functions facing each landlord change for two reasons: first, the amenity improvement at each location may affect the marginal price and marginal cost of Z even if the hedonic remains unchanged; second, the hedonic will probably change. Because we lack complete analytic understanding of the determinants of the hedonic price function, it seems difficult to make any general statement about what will happen to marginal prices of Z if amenities improve and the hedonic function shifts. However, it would seem an extraordinary stroke of luck if the same Z were to satisfy both equation 8a and equation 8b.

It is perhaps more reasonable to assume that landlord supply of most housing characteristics will not change much in the short-run, due to the durability of housing capital, and high alteration costs. If this assumption holds, and households do not move in the short-run because of moving costs, then we may interpret the usual benefit measure as a short-run measure. In the short-run, it may not be unreasonable to assume that households and landlords do not adjust very much to amenity improvements, because of moving costs, the durability of housing, etc. The usual benefit measure might then be adequate as a short-run benefit measure. Over the longer-run, as adjustment occurs, the usual benefit measure will become more and more of an underestimate.

3.2 The Property Value Increases Predicted by the Original Hedonic Function Due to Amenity Improvements will Overestimate True Benefits

An overestimate of true benefits is provided by the hypothetical property value increases that would be caused by amenity improvements if the hedonic property value function remained unchanged. I emphasize that these predicted property value increases are purely hypothetical, because the hedonic property value function would generally be expected to change after the amenity improvements.

In a similar approach to the previous section, this benefit measure can be shown to be an overestimate by considering the effects of the amenity improvements in three hypothetical stages. In the first stage, the amenity improvements take place, but the hedonic price function remains unchanged. Landlords adjust their housing supply to the desired level given the new level of amenities and the old hedonic price function. Households are moved to their new location. In the second stage, landlords' housing supply choices are adjusted to the level they will choose after the hedonic price function has shifted. Finally, at the third stage, the hedonic price function shifts, and rents at all locations change to their final equilibrium levels. Table 2 gives algebraic formulas for household and landlord benefits at each stage.

At the first stage, households must lose because they are moved from an equilibrium position to a new location that will not generally offer the same housing and amenity characteristics as their original equilibrium, yet the hedonic price function has not changed. Landlords' profits increase for three reasons: the increase in the rents they can obtain caused by the amenity improvements; any cost savings provided by the amenity improvements; and their profit-maximizing housing stock adjustments in response to these price and cost changes. In a competitive property market, differences in landlord profits across location must be reflected in property values. The property value increases resulting in the first stage from the amenity improvements would be predicted by a hedonic property value model, estimated using the pre-improvement equilibrium values, that related property values to amenities and other variables.

At the second stage, landlords must lose profits. The hypothetical change in the second stage moves landlords from their equilibrium housing stock choices to housing stock levels that are out of equilibrium given that the hedonic price function has not yet shifted. The housing stock change at each location may make households better or worse off than they were after the first stage, but they must still be worse off than they were at the initial equilibrium, given that the hedonic price function has not shifted.

Finally, the third stage changes yield no net efficiency benefits. The rent changes are simply a pecuniary transfer between landlord and tenant.

Taking the benefits of all three stages together, total social benefits must be equal to the first-stage increase in landlord profits plus two changes that move households and landlords out of equilibrium, and therefore must be net costs. Hence, the first-stage increase in landlord profits will always be an overestimate of total social benefits. As mentioned before, this first-stage increase in profits can be measured, in capitalized form, by the predicted change in property values due to the amenity improvements, based on a hedonic model estimated using original equilibrium property values and amenity levels.

This proposed upper-bound benefit measure is not the same as the rent increases due to amenity improvements that would be predicted by the original hedonic rent function. As can be seen by the discussion above, landlord profits increase at the first stage not only because rents increase due to amenity improvements, but also because of cost savings and housing stock adjustments. Even if it is plausible to assume that cost savings are zero, housing stock adjustments would be expected to positively affect profits. Hence, the rent increases due to amenity improvements may be an over- or under-estimate of total social benefits, depending on the algebraic sign of the sum of profit increases due to first-stage housing stock adjustments, plus the profit decreases due to second-stage housing stock adjustments, plus cost savings, plus the disequilibrium losses to households at the first stage. These hypothetical rent increases would probably be an overestimate if amenity-induced cost savings are small, and if the net housing stock changes from the first and second stages are small, i.e., the final equilibrium housing stock chosen by landlords does not differ greatly from the original equilibrium.

This hedonic property value benefit measure will be an exact measure of true social benefits, rather than an overestimate, if the hedonic plus two changes that move households and landlords out of equilibrium, and therefore must be net costs. Hence, the first-stage increase in landlord profits will always be an overestimate of total social benefits. As mentioned before, this first-stage increase in profits can be measured, in capitalized form, by the predicted change in property values due to the amenity improvements, based on a hedonic model estimated using original equilibrium property values and amenity levels.

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This hedonic property value benefit measure will be an exact measure of true social benefits, rather than an overestimate, if the hedonic vary across markets. Hence, it seems quite likely that in many cases benefit analysts will not be able to consistently estimate marginal bid functions.

I propose that in these situations analysts should give careful consideration to the hedonic property value measure as an approximation to true benefits. Although this measure is an overestimate, the approximation may not be too bad when compared with other potential sources of error in the analysis.

The error in using the hedonic property value measure is bounded by the difference between this measure and the household valuation measure. At each location, this is the difference between the effect of a given amenity improvement on property values and the valuation by the current household of that amenity improvement. As mentioned above, the amenity improvement increases property values because it increases rents, reduces landlord costs, and leads to housing stock readjustments. Assume, as seems reasonable, that the latter two effects on profits and property values are relatively small compared to effects of the amenity-induced increase in rents. Then the possible overstatement will be roughly bounded by the difference between the amenity improvement's effect on rents and its valuation by the original occupant of the site.

From the basic theory of hedonics, it is clear that if an amenity improvement causes a particular increase in rents, then at least some households must value that improvement by more than the rent increase, or the higher amenity sites would never be chosen. Hence the basic question is how much less the original occupants value the improvement than households who choose higher amenity levels. From a purely theoretical perspective, no answer can be given to this question. But if the original occupants and households choosing these higher amenity levels do not differ greatly in income or other demand determinants, it seems plausible that their valuation of the amenity improvement may not differ much either.

For example, consider an amenity improvement that increases rents at a given location by five percent. This market rent effect implies that households who originally chose the higher amenity level value this amenity increment by more than five percent. If the original occupants of the site are similar in many respects to those who originally chose the higher amenity level, than their valuation of the amenity may not be much less than five percent.

One empirical example that shows only moderate differences between hedonic rent increases and household valuations is a study by Bartik (1983) that focused on the amenity "physical condition" of a neighborhood. Bartik found that rent increases caused by a one standard deviation increase in this amenity were about twice the original occupant's valuation.

Of course, the attractiveness of using the hedonic property value measure will depend upon the degree of accuracy that is deemed desirable or achievable in the benefit analysis. From the above example, it seems clear that the hedonic property value measure might well lead to a two-fold or three-fold overstatement of benefits. My own view is that we are deluding policymakers if we pretend that most hedonic benefit estimates are accurate to a greater degree than this even without this approximation. Given the enormous difficulties in measuring amenities, problems in specifying the hedonic function, and the many unmeasured variables affecting housing prices, a three-fold error may not loom large in comparison. Any analyst who pretends to a greater degree of accuracy has probably not looked closely at his data or assumptions, and is misleading his readers if not himself.

5. CONCLUSION

This paper has shown that the usual benefit measure for amenity improvements, household valuations of the change at their original location, is likely to be incorrect. The basic intuition is that it is fundamentally inconsistent to use the hedonic model, which is premised on household and landlord adjustment in response to the hedonic function, and then ignore such adjustment in computing benefits. The true measure is shown to be infeasible, but some practical alternatives are proposed. The discussion suggests two possible lines of research. First, the possibility of calculating the true benefit measure using simulation methods should be explored. This research should examine how good various approximations to true benefits are under different assumptions. Second, further estimates of marginal bid functions, and their comparison with hedonic price functions, should be undertaken. This would enable a better assessment of whether hedonic property value measures are likely to overstate benefits by two-fold, or ten or twenty-fold. If the latter is true, the hedonic property value measure is unlikely to be of much use by itself as a benefit measure.

Footnotes

[1]I have benefitted greatly from several conversations with Kerry Smith on the topics discussed in this paper. Portions of this research were funded by the Environmental Protection Administration.

[2]The bid function is formally defined as the function E(A, Z, y, v_1) that solves $U(Z, A, y - E) = v_1$, where U( ) is the utility function of the household defined over Z, A, and non-housing expenditure, and y is household income. The income term is suppressed in the text because it does not change.

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Table 1. A Decomposition of the Benefits of Amenity Change into Household Willingness to Pay and a Non-Negative Quantity

Benefits at Various Stages to:

	Household i	Landlord j	Society
Stage 1: Amenity changes, no adjustment or rent change	$E(A^a_{oi}, Z^b_{oi}, v_i) - E(A^b_{oi}, Z^b_{oi}, v_i)$ Household willingness to pay (WTP) at original location	$-[C(A^a_j, Z^b_j) - C(A^b_j, Z^b_j)]$ Landlord cost savings: assumed positive	Sum of all household WTP plus all landlords' cost-savings
Stage 2: Rent change	$-[p^a(A^a_{oi}, Z^b_{oi}) - p^b(A^b_{oi}, Z^b_{oi})]$ Rent change	$[p^a(A^a_j, Z^b_j) - p^b(A^b_j, Z^b_j)]$ Rent change	Zero efficiency benefits; pecuniary transfer from households to landlords
Stage 3: Adjustment	$E(A^a_{ni}, Z^a_{ni}, v_i) - p^a(A^a_{ni}, Z^a_{ni}) -$ $[E(A^a_{oi}, Z^b_{oi}) - p^a(A^a_{oi}, Z^b_{oi})]$ Household utility increase from adjustment to new hedonic	$p^a(A^a_j, Z^a_j) - C(A^a_j, Z^a_j) -$ $[p^a(A^a_j, Z^b_j) - C(A^a_j, Z^b_j)]$ Landlord profit increase from adjustment to new hedonic	Net gain from adjustment must be non-negative for all
Sum of Three Stges	$E(A^a_{ni}, Z^a_{ni}, v_i) - E(A^b_{oi}, Z^b_{oi}, v_i) -$ $[p^a(A^a_{ni}, Z^a_{ni}) - p^b(A^b_{oi}, Z^b_{oi})]$ Same as Eq. 1 in text; Net household gain	$p^a(A^a_j, Z^a_j) - C(A^a_j, Z^a_j) -$ $[p^b(A^b_j, Z^b_j) - C(A^b_j, Z^b_j)]$ Same as Eq. 2 in text; Net landlord gain	Same as Eq. 3 in text = household WTP at original location plus non-negative quantity

Table 2. A Decomposition of the Benefits of Amenity Change into Landlord Profit Gain at Original Hedonic Plus Non-Positive Quantity

Benefits at Various Stages to:

	Household i	Landlord j	Society
Stage 1:	$E(A^a_{ni}, Z^*_{ni}, v_i) - p^b(A^a_{ni}, Z^*_{ni}) - [E(A^b_{oi}, Z^b_{oi}, v_i) - p^b(A^b_{oi}, Z^b_{oi})]$	$p^b(A^a_j, Z^*_j) - C(A^a_j, Z^*_j) - [p^b(A^b_j, Z^b_j) - C(A^b_j, Z^b_j)]$	Increase in landlord profits under old hedonic plus artificial household disequilibrium
Amenity changes, hedonic price function does not change, household moved to new location, landlord partially adjusts	Effect on household of moving to new location even though hedonic has not changed. Negative unless $(A^a_{ni}, Z^*_{ni}) = (A^b_{oi}, Z^b_{oi})$. Z* is level of Z chosen by landlord subject to new amenity, old hedonic	Effect on landlord profits of amenity change and adjustment, keeping hedonic fixed: assumed to be non-negative	
Stage 2:	$E(A^a_{ni}, Z^a_{ni}, v_i) - p^b(A^a_{ni}, Z^a_{ni}) - [E(A^a_{ni}, Z^*_{ni}, v_i) - p^b(A^a_{ni}, Z^*_{ni})]$	$p^b(A^a_j, Z^a_j) - C(A^a_j, Z^a_j) - [p^b(A^a_j, Z^*_j) - C(A^a_j, Z^*_j)]$	Net effect of Stage 1 and 2 is increase in landlord profits at Stage 1 plus disequilibrium losses.
Landlord's supply adjusted to final level	Uncertain sign. But Stage 1 and 2 summed must be negative because hedonic has not changed, (Z, A) consumed has changed	Landlord loses profits because of change away from equilibrium Z*, given A^a and old hedonic	

Table 2. (continued)

Stage 3: Hedonic changes	$-[p^a(A^a_{ni}, Z^a_{ni}) - p^b(A^a_{ni}, Z^a_{ni})]$ Rent change	$p^a(A^a_j, Z^a_j) - p^b(A^a_j, Z^a_j)$ Rent change	Zero efficiency benefits
Sum of Three Stages	$E(A^a_{ni}, Z_{ni}, v_i) - E(A^b_{oi}, Z^b_{oi}, v_i) -$ $[p^a(A^a_{ni}, Z^a_{ni}) - p^b(A^b_{oi}, Z^b_{oi})]$ Same as Equation 1 in text	$p^a(A^a_j, Z^a_j) - C(A^a_j, Z^a_j) -$ $[p^b(A^b_j, Z^b_j) - C(A^b_j, Z^b_j)]$ Same as Equation 2 in text	Same as text equation 3 = Increase in landlord profits under old hedonic plus non-positive quantity

SUPPLY UNCERTAINTY, OPTION PRICE, AND INDIRECT BENEFIT ESTIMATION

V. Kerry Smith*

I. INTRODUCTION

Both the original and many of the subsequent explanations of the concept of option price have been motivated by an assumption of an uncertain supply of the commodity involved.[1] Consequently, it is surprising to find that all of the definitions of option price compare two states of the world that each have known (or certain) supply conditions. Paying the option price does not eliminate supply uncertainty, as it has been described. Rather it changes the individual's conditions of access to the good or service from a certainty of no access to a certainty of complete access. Risk enters the problem only because these analyses assume the individual does not know whether he (or she) will desire access at the time the payment must be made. Since the analysis is in terms of planned consumption, the reason for this demand uncertainty is sometimes explained by the fact that the consumption must take place in the future, when other factors influencing demand may have changed.[2]

Bishop [1982] appears to have been the first to draw attention to this omission of supply uncertainty and proposed a framework without demand uncertainty to demonstrate that there are conditions when option value (i.e., the difference between option price and the expected consumer surplus) would be unambiguously positive.[3]

While there have been a number of theoretical refinements to this structure, there has been little progress in the measurement of option price.[4] Indeed, there seems to be a consensus that the estimation of option price will require survey techniques which provide an explanation of the concept and then elicit individuals' responses.

The purpose of this paper is to consider the interpretation of the marginal willingness to pay estimates derived using indirect methods, such as the hedonic property value or wage models.[5] While it has been recognized since the work of Thaler and Rosen [1975] that the slope of hedonic functions (wage or property value) provide a point estimate of the marginal valuation of the risk change, the specific interpretation of these marginal values has never been fully explored.[6] We will demonstrate that they provide point estimates of the gradient of the option price -- risk schedule, when the option price is considered a payment for a change in a set of uncertain supply conditions. To illustrate the potential policy implications of this interpretation, two recent hedonic property value studies are discussed as examples.

II. <u>OPTION PRICE AND CHANGES IN ACCESS CONDITIONS</u>

To define option price under the conventional "timeless" framework assume an individual's preferences can be described using state dependent utility functions. Each utility function is assumed to be well-behaved and a function of the income realized in each state. Under the conventional definition an option price (that was different from the expected consumer surplus) arose because the individual was uncertain which state would describe his (or her) preferences.[7] Our analysis will follow Bishop [1982] in that the state dependency will be associated with the supply conditions. For example, if the commodity is some dimension of environmental quality, then the differing supply conditions might involve varying levels of air quality -- such as conditions leading to poor visibility or acute health effects versus a relatively unpolluted situation. It is reasonable to expect that these differences would affect an individual's ability to enjoy income and hence the marginal utility of income.[8] This type of effect would imply a state dependent description of preferences as a function of income.

Without loss of generality we can describe this problem using two states, with $U_1(.)$ representing the utility realized under the desirable state and $U_2(.)$ the undesirable. By definition the desirable and undesirable states are not known with certainty. p defines the probability of the desirable state and (1-p) the undesirable. In this framework, the conventional definition of option price, OP, would be the maximum payment to assure the desirable state as given in equation (1).

$$U_1 (Y_1 - OP) = p\, U_1 (Y_1) + (1-p)\, U_2 (Y_2) \qquad (1)$$

In this case the payment of OP resolves the uncertainty.[9] By contrast, suppose that the payment simply increased the likelihood of the desirable state. Analytically this would be described by equation (2), with σ representing the increase in the probability of the desirable state secured by paying OP.

$$(p + \sigma) U_1 (Y_1 - OP) + (1-p-\sigma) U_2 (Y_2 - OP) = p U_1 (Y_1) + (1-p) U_2 (Y_2) \qquad (2)$$

This formulation is clearly relevant to the examples cited above. It is also appropriate for both Bishop's theoretical arguments and the empirical example presented recently by Brookshire, Eubanks, and Randall [1983].

If we allow σ to change incrementally and observe the change in OP required to maintain constant expected utility at $p U_1 (Y_1) + (1-p) U_2 (Y_2)$ then we can define an option price-risk schedule with a slope given by (3).

$$\frac{dOP}{d\sigma} = \frac{U_1 (Y_1) - U_2 (Y_2)}{(p + \sigma) \frac{dU_1}{dY_1} + (1-p-\sigma) \frac{dU_2}{dY_2}} \qquad (3)$$

A point estimate of this gradient can be derived from the hedonic property value model by considering the individual's equilibrium choice of risk indirectly through his (or her) housing location decisions. To establish this result, assume the individual must select a residential location and receives with it a bundle of attributes, a_1, a_2, ..., a_n, as well as a probability of experiencing the desirable outcome, p. If these attributes and probability are recognized by all individuals in the market for sites (both demanders and suppliers), the equilibrium prices of sites will reflect all of these attributes including p. Conventional practice maintains that we can describe these prices with a function, r(·) -- the hedonic price function. Moreover, we can expect that in equilibrium the individual will select a site where the marginal contribution of an increment in p to the price equals the individual's marginal rate of substitution between p and Y, MRS_{pY} or:

$$\frac{\partial r(a_1, \ldots a_n, p)}{\partial p} = MRS_{pY} \tag{4}$$

If we further extend the framework by specifying a role for $a_1, \ldots, a_n$ in the individual's utility function, then the right side of equation (4) reduces to the expression on the right hand side of (3) with = 0 (i.e., the increment begins from p). Thus, the derivative of the hedonic price function with respect to risk (i.e., the probabilities of events) provides a point estimate (in equilibrium) of the slope of the option price-risk schedule. While this conclusion has not previously been recognized, it should not be surprising. Once uncertainty is introduced into the modeling of choices in a hedonic framework, the individual is making ex ante decisions in the selection of a site to obtain a probability (p) along with the other site attributes. The process defining an equilibrium implies selections at the margin with payments for increments in the risk irregardless of the outcome of the uncertain process. Hence, the incremental option price as defined in (3) is in fact being paid before the events at risk are realized (and will necessarily be constant under all states of the world).

III. SOME EXAMPLES

Two recent applications of the hedonic property value framework have treated cases that are relevant to this framework. The first by Brookshire et. al. [forthcoming] examines whether information on the differential levels of damage to residential structures as a result of earthquakes in Los Angeles and San Francisco is a significant determinant of property values in each city. Their measure for risk is a discrete variable -- whether the home is in a zone with a higher expected level of damage or in zones expected to be at the average level. Clearly, in this case, a site selection is made and premium paid before the event (i.e., earthquake with severe damage) is realized. The property value differential can be expected to reflect the option price for the reduction in perceived risk. Though in this case the discrete nature of the choice makes it difficult to infer an estimate of the option price-risk gradient from their estimates.

A second example concerns risks of exposure to hazardous wastes in Boston and a hedonic model developed by Harrison and Stock [1984]. In this case, a function of distance from the property to hazardous wastes disposal sites and the size of the disposal sites is treated as a proxy for risk of exposure to these wastes. Assuming this association between distance and risk is reasonable, then increments in property values associated with increased distance also represent payments for reductions in the likelihood of exposure before the outcome of the uncertain process (i.e., exposure versus not exposure in the simplest terms). Thus, assuming equilibrium, it should be interpreted as a point estimate of the increment to the option price.

These examples illustrate that it is feasible, in principle, to develop point estimates of the slope of the option price-risk schedule. Estimates of the option price for a discrete risk change would require knowledge of how this slope varies with risk. This is an identification problem quite comparable to that posed in using the hedonic model to estimate the demand for any other site attribute and can, in principle, be resolved in similar terms.[10]

FOOTNOTES

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1. The concept was introduced by Weisbrod [1964] and has found its most direct applications in the evaluation of environmental resources, following the early arguments of Krutilla [1967].

2. Hartman and Plummer [1982] appear to have been the first to suggest this explanation in formal terms using price and income uncertainty. For a discussion of their arguments, see Freeman [1984a].

3. More recently, Freeman [1984b] has considered the possible interaction of demand and supply uncertainties in considering the relationship between demand and supply uncertainty. Smith [1983] also treated a somewhat different form of supply uncertainty together with demand uncertainty to establish that option value could be positive.

4. To date there have been four attempts to measure option price and option value: Greenley, Walsh, and Young [1981], Brookshire, Eubanks, and Randall [1983], Desvousges, Smith, and Fisher [1983], and Walsh, Loomis, and Gillman [1984]. All have relied on survey techniques.

5. This statement assumes that the two functions can be considered independently. That is, in some cases, such as risk on the job, a hedonic wage model would be the appropriate basis

for estimating the slope of the option price -- risk at the point of equilibrium. In others, such as risk of exposure to hazardous wastes from local disposal sites, the hedonic property value would be more relevant. When adjustment to risk can effect decisions in both markets the relationship will depend on how households are assumed to adjust. In describing such cases both Rosen [1979] and Roback [1982] have assumed a change of housing site necessarily implies a change in job. In that framework both functions serve to define the individual's marginal willingness to pay for a site attribute. See Bartik and Smith (forthcoming) for a more complete discussion of these models.

6. One notable exception is Marshall's [1984] recent paper on the use of hedonic models to value small changes in the risks of death. While his analysis specifically recognizes the ex ante nature of the decision making, it does not relate the compensating differences in wages (in a hedonic wage framework) with risk to the option price.

7. See Bishop [1982] and Smith [1983] for reviews of this literature.

8. Some time ago Arrow [1974] offered a strong argument for state dependent preferences in another context. However, it is equally relevant to a large number of environmental policies. He observed that:

> "...income is not the only uncertainty, especially in the context of health insurance, and only under special and unrealistic circumstances can it be held that the other uncertainties have income equivalents. Put loosely, the marginal utility of income will in general depend not only on the amount of income but also on the state of the individual, or more generally, on the state of the world." (p. 2)

9. With demand uncertainty, as the original definitions of option price were proposed, the payment of the option price would affect access to a resource and thereby add another argument in the state dependent utility functions. Thus, if $U_i = U_i(Y, A)$ with A=a defining access and A=0 no access, the option price for this case (with state-dependency arising because one influence to demand, such as the price of a substitute, being uncertain) the option price would be defined as:

$$p U_1(Y_1 - OP, a) + (1-p) U_2(Y_2 - OP, a) =$$

$$p U_1(Y_1, 0) + (1-p) U_2(Y_2, 0)$$

10. For an overview of the identification problems with hedonic models, see Brown (1983) and Bartik and Smith (forthcoming).

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Part II

Conceptual Issues in Valuation Under Uncertainty

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INTRINSIC AND ECOLOGICAL BENEFITS OF HAZARDOUS WASTE REGULATIONS

by

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This paper was prepared as part of the project on The Benefits of Hazardous Wastes Management Regulations Using Contingent Valuation, Vanderbilt University Cooperative Agreement--CR811075, with U.S. Environmental Protection Agency.

I. INTRODUCTION AND OVERVIEW

The basic purpose of this paper is to develop a framework for defining and measuring the economic values of ecological changes, especially values unrelated to the direct use of the environment, and to investigate the available techniques for estimating these economic values. The focus of this paper is on ecological changes associated with the release of hazardous waste materials into the environment. Such releases are presumed to degrade the economic value of ecosystems. Conversely regulatory policies which reduce the volume of hazardous materials escaping to the environment or which reduce the probabilities that releases occur yield benefits in the form of avoided damages. The focus of this paper is on the benefits of these regulations, that is, the economic damages they avoid or prevent.

The perspective adopted in this paper is anthropocentric. Our concern is with those types of ecological effects which individuals (both users and nonusers of particular ecosystems) are likely to place values on. Thus only those features of the environment which are arguments in individuals' preference orderings or utiity functions can be said to have economic values attached to them.

This point of view is in contrast to that adopted by some ecologists who have written about the economic valuation of ecosystem functions. For example, Gosselink, Odum, and Pope (1974) suggested that the economic value of a tidal marsh could be estimated by determining the cost of carrying ut certain functions such as nutrient removal by other means. And Westman (1977) suggested that ecosystem impacts that result in decreases in ecological functions could be valued at the cost of replacing those functions. For example, if a hazardous material reduces nitrogen fixation in soils, they suggest that the damage could be calculated from the costs of manufacturing and applying an equivalent amount of chemical nitrogen fertilizer. These replacement cost measures could be an appropriate basis for economic valuation if the replacement activities were actually undertaken. That would be an indication that the economic value of the ecological functions equaled or exceeded the replacement cost at the margin. But the ecological functions lost might have little or no value at the margin, in which case they would not be replaced. And replacement cost would be an inappropriate basis for determining value.

Ecological systems can yield benefits to people in a variety of forms. For example, both managed and natural ecosystems can yield food or fiber for market. In such instances, the ecological system is an input to a production process which also involves capital and labor in the cultivation and harvest of plant and animal species. We might call these production or market benefits because the harvest activities are undertaken in response to market forces and profit incentives. The benefits of changes to ecosystems used for market purposes come in the form of changes in the prices of goods and factor inputs. This is in contrast to those human actions involving use of the ecological system where the use yields utility directly to the individuals concerned. Examples of such direct use benefits include the values attributable to recreation activities such as hunting, fishing, wildlife observation, and nature photography.

It has also been argued that natural environments including their ecological components can yield benefits to people which are not associated with the direct use of the environment. This class of benefits has been variously named intrinsic, nonuser, and nonuse benefits. Such benefits are said to arise from a variety of motives, including placing value on the knowledge on the existence of a particular environmental or ecological attribute, a desire to bequeath certain environmental assets to one's heirs or to future generations, or sense of stewardship or responsibility for preserving certain features of natural environments.

One of the objectives of this paper is the development of a logical and consistent set of definitions and concepts that can guide further theoretical development and empirical testing. Toward this end, section III is devoted to a systematic examination of the several types of intrinsic benefits associated with ecological change that have been discussed in the literature.

In section IV, I consider alternative ways of specifying preference functions to reflect the various forms of intrinsic benefits. One issue to be addressed in this section is under what circumstances is it possible (or meaningful) to attempt to partition a total benefit measure into components, for example, use, bequest, pure existence, and so forth. Another issue concerns the relationship between intrinsic benefits and the benefits associated with the direct use of the environment.

Some authors have considered option value to be a form of intrinsic benefit. Option value over and above the expected use value is said to arise because of uncertainty about the future supply or availability of certain features of the ecological system, especially when the individual may be uncertain also about his own future demand. In section V, I review some recent developments in the theory of option value, present some new results, and consider their implications for the valuation of ecological change under conditions of uncertainty. I also show that option value can be considered to be the algebraic difference between two different types of welfare measure, an ex ante measure (the maximum sure payment that can be extracted before the resolution of uncertainty) and an ex post measure (the expected value of the maximum payment which can be extracted in each state of the world after the resolution of uncertainty). Thus the role of option value in the assessment of welfare changes depends in part on which form of welfare measure is appropriate. This issue is also addressed in section V.

The major objective of this paper is to identify techniques or methods for the empirical measurement of the various forms of intrinsic benefits, and for testing hypotheses about the size and determinants of intrinsic benefits. Since intrinsic benefits are those benefits that are not related to the use of ecological systems, it is not possible to draw inferences about the magnitude of intrinsic benefits from observations of such market related variables as travel costs of users. Rather, intrinsic benefits, by their nature, must be estimated through contingent valuation and related methods. The purpose of a contingent valuation question is to test hypotheses about both the magnitude of intrinsic and ecological values and the features of the ecology that matter to people, that is, what kinds of effects are most important to them. Hypotheses that are worthy of investigation include the following:

1. Intrinsic and nonuse values associated with ecosystem changes are significantly greater than zero.
2. People have a higher willingness to pay to avoid ecological changes affecting large areas and/or persisting for long periods of time as compared with those effects which are localized and/or temporary.
3. There are significant differences in expressed willingness to pay to avoid changes in different ecological end points or to avoid changes in the populations of different plant and animal species.
4. Is it possible empirically to distinguish among values due to a bequest motivation, values due to a sense of stewardship or a desire to protect certain species, etc.?

Section VI draws some conclusions about the design and implementation of contingent valuation studies focusing on intrinsic benefits.

If individuals are to be asked contingent valuation questions about the intrinsic values of ecological changes, they must be presented with plausible and reasonably specific descriptions of these changes. The next section presents a discussion of possible ecological consequences of hazardous waste management practices.

II. HAZARDOUS WASTE MANAGEMENT AND ECOLOGICAL EFFECTS

The purpose of this section is to draw on existing knowledge of categories of hazardous materials and classifications of the effects of such materials in the environment to construct one or more plausible scenarios describing how hazardous waste management regulations might generate ecological and intrinsic or nonuse benefits to people. The point of view adopted in the development of these scenarios is anthropocentric. That is, our concern is with those ecological effects that alter human uses of the environment or that alter features of the ecology that are likely to be important to individuals, such as the populations of certain flora and fauna.

In this section, I first develop a simple classification of hazardous materials based upon their toxicity and degree of persistence in the environment. I then develop a classification of ecological effects according to the principal ecological end points. This section concludes with descriptions of alternative scenarios of hazardous waste releases to the environment and their ecological consequences. The purpose of hazardous waste regulations is to reduce the probability of such releases and/or the extent of ecological changes that result. Thus these scenarios can provide a basis for describing the potential benefits (damages avoided) of hazardous waste regulations.

In a recent study of instances of environmental contamination by hazardous materials, the Environmental Protection Agency (1980, p. vi) offered a classification of hazardous substances into six categories reflecting the functional characteristics of substances in commerce and industry and their chemical characteristics. The following is a brief discussion of the most likely major environmental impacts and fates of each of these categories.

Solvents and Related Organics. This category includes such substances as benzene, trichloroethylene, chloroform, and toluene. Many of these substances are acutely toxic in high doses to humans and other organisms. On the other hand, most of these substances disperse rapidly in the environment and are subject to breakdown to relatively inocuous substances by a variety of chemical and biological processes. Accordingly they have relatively short half lives in the environment. Some of these substances are known or suspected human or animal carcinogens and thus present a potential threat to human health through long term, chronic exposures at low levels. But due to the short half lives of these substances, such long term chronic exposures are not likely except in the case of contamination of biologically inactive ground water aquifers or in the case of biogenic sources such as chlorination of drinking water containing naturally occurring organic compounds.

PCBs and PBBs. The polychlorinated and polybrominated biphenyls are not readily degraded in the environment. PCBs are known to be widely dispersed throughout the environment; and detectable amounts of PCBs are present in the atmosphere around the earth, in the water column and sediments, and in the tissues of a variety of organisms (National Academy of Sciences, 1979). PCBs can cause a variety of adverse effects on nonhuman species and have been classified as a possible human carcinogen (International Agency for Research on Cancer, 1979).

Pesticides. This is a heterogeneous category in terms of environmental impacts and persistence. Some types of pesticides, for example, the organo-phosphates, are acutely toxic but degrade quickly in the environment under most conditions and are not subject to bioaccumulation. On the other hand, the chlorinated hydrocarbon pesticides have long half lives in the environment and are subject to bioaccumulation. Long term exposures to these substances, even at low levels, are known to have adverse effects on nonhuman species. And several of these substances are suspected human carcinogens.

Inorganic Chemicals. This category includes such things as ammonia, cyanide, and various acids and bases. While many of these substances may be highly toxic and/or corrosive, they tend to have short half lives in the environment because of processes such as oxidation (for example, cyanide) or neutralization.

Heavy Metals. Examples include mercury, lead, chromium, and cadmium. Heavy metals are obviously persistent in the environment. But they may become immobilized in sediments. Not all chemical forms of heavy metals are biologically active. But some forms of heavy metal compounds are subject to bioconcentration. Some compounds are known to be toxic at relatively low doses over long periods of time. And some are known or suspected carcinogens.

Waste Oils and Grease--some components of waste oils and grease may be toxic and/or carcinogenic. But most of the components of waste oil and grease are biodegradable and have relatively short half lives in the environment. Waste oils are often contaminated with heavy metals and persistent organic compounds such as PCBs.

In terms of environmental impacts the categories of hazardous materials described here differ primarily with respect to two characteristics, toxicity both to humans and other organisms (acute vs. chronic) and environmental persistence (highly persistent vs. relatively short half lives). Furthermore those substances which are acutely toxic also tend to have short environmental half lives, while those substances which are toxic in chronic, long term doses (some of which are known or suspected carcinogens) also tend to be highly persistent in the environment. For this reason two types of scenarios will be constructed below. One type will involve large quantities of acutely toxic substances with short environmental half lives, for example organic solvents, some forms of pesticides, and inorganic chemicals such as cyanide and acids. The other type will involve quantities of environmentally persistent and chronically toxic substances such as PCBs, some forms of pesticides, and heavy metals.

There are several possible ways of classifying the ecological effects of the release of hazardous wastes into the environment. The most useful one for the purposes of this paper is based on the different types of ecological end points Barnthouse, et al., (1982). It should be noted that these end points were identified to provide a basis for environmental risk analysis for synthetic fuels projects. Therefore not all of these ecological end points would be of equal importance for the analysis of hazardous waste regulations. Five types of ecological end points were identified by Barnthouse, et al. These end points were identified because each could be clearly defined, was quantifiable, and described impacts of potential importance to humans. This is not intended to be an exhaustive listing of possible ecological consequences.

1. Reductions in Commercial or Game Fish Populations. Because of their position in the food chain, these fish populations are often sensitive indicators of the ecological health of aquatic ecosystems. And these populations sustain important commercial and recreational activities. This end point could also include the replacement of more desirable fish species with less desirable species (e.g. carp for bass).

2. Increases in the Populations of Nuisance Species of Algae. Increases in the concentration of blue-green algae are often the consequence of pollution induced increases in the availability of certain nutrients. Blooms of blue-green algae indirectly affect human welfare through adverse impacts on drinking water quality and the amenity aspects of water based recreation. They may also contribute to other ecological changes such as reductions in the populations of desirable fish species.

3. Reductions in Forest Growth and Changes in the Composition of Plant Species. Reductions in forest growth have a direct economic significance, and may also affect amenity values. Changes in plant species can affect both recreation and amenity values and the ability of the terrestrial ecosystem to support mammalian and

bird species.

4. Reductions in Agricultural Production. Reductions in agricultural productivity are of direct economic significance. They lie outside the scope of this research project.

5. Reductions in Wildlife Populations. Reductions in wildlife populations can occur because of direct toxicity to species of concern, the modification of habitat, or modification of the food chain.

The objective of this exercise is to identify scenarios of hazardous waste spills or uncontrolled releases and the associated ecological impacts so that realistic and plausible descriptions of these events can be used for contingent valuation surveys. It should be noted that the scenarios described below are not meant to reflect all possible significant events and ecological end points. Rather they are meant to be representative of the more typical or more likely events involving hazardous wastes and events for which significant ecological and intrinsic benefits are likely. Thus scenarios involving primarily market or production values (for example, agricultural productivity, commercial fisheries, human health risks, or water supplies) are not represented below.

Scenario A: Long term effects on aquatic ecosystems

Substances: Polychlorinated biphenyls (PCBs), chlorinated hydrocarbon pesticides, or heavy metals such as mercury, lead, or cadmium. Substances like these have the characteristics of persistence in the environment, bioconcentration or bioaccumulation, and chronic toxicity for a variety of species, especially those at higher trophic levels.

Event. Unregulated disposal or the breakdown of a poorly designed disposal site leads to the more or less continuous release of the substance into the environment. Environmental transport via runoff, leaching, or migration through soils results in the substance reaching surface water systems. As a result the substance is widely distributed throughout the aquatic ecosystem.

Impacts: The accumulation of the substance in the food chain is likely to lead to reductions in the populations of sensitive species and their predators (e.g. fish, and fisheating mammals and birds such as ospreys and eagles). Also accumulation of the substance in body tissues could render species of game fish unsuitable for human consumption.

Forms of Economic Damages: (1) Use values--the contamination of the tissues of fish or reductions in their populations would result in loss of recreation use values. Reduction in the population of water fowl due to direct toxicity or changes in the food chain could affect recreational hunting and viewing uses. There could also be losses of user amenity values to the extent that reductions in the populations of non-game fish and the mammals and birds which feed on them (e.g., otters, seals, loons, ospreys), reduced the oportunities for wildlife observation. (2) Nonuse/intrinsic values--there could be existence, preservation, or option values associated with avoiding threats to the populations of species of aesthetic or emotional significance, for example, bald eagles, loons, or seals.

Examples: The following actual cases described in U.S. Environmental Protection Agency (1980) are illustrations of this type of scenario: Hooker Chemical, Montague Plant, Muskegon, Michigan, 1979 (page 18); Waste Industries, Inc., New Hanover County, 1980 (page 29); ABM Wade, Pennsylvania (page 35), and Taft Forge, Inc., Howell, Michigan (page 125).

Scenario B: Long term localized effects on terrestrial systems.

Substances: PCBs, or other organic chemicals.

Event: Poor disposal or storage practices lead to the contamination of soils in a localized area.

Impacts: Changes in local plant and animal populations.

Form of Economic Damages: (1) Use Values--Losses to recreation hunters and to bird and other wildlife viewers. (2) Non-user/Intrinsic Values--Reduction in diversity of plant population: reduction in local populations of mammalian and bird predators.

Examples: The following actual cases described in U.S. Environmental Protection Agency (1980) are illustrations of this scenario. Byron, Illinois (p. 81); Winslow Township, New Jersey (p. 162); Trenton, New Jersey (p. 172); West Glens Falls/ Queensbury, New York (p. 175); Oswego, New York (p. 185).

Scenario C: Short term acute effects.

Substances: Organic solvent, acid, or inorganic toxic such as cyanide. Such substances are acutely toxic but have relatively short environmental half lives.

Event: An accidental spill or breach from a poorly designed containment such as a lagoon. The substance quickly spreads to nearby streams or lakes.

Impacts: Heavy losses of aquatic organisms including fish, and possible losses of fish-eating species. Because of dilution, neutralization, and/or biodegradation, concentrations of the substance in the environment fall to background levels relatively rapidly. Species populations recover through recolonization and in-migration.

Forms of Economic Damages: (1) Use values--activities such as sports fishing and boating are adversely affected until the toxic materials are dispersed or neutralized and the populations of the target species restore themselves. The magnitude of the welfare losses to users may be relatively low if there are alternative sites supporting this activity which remain unaffected by the event. (2) Nonuser/Intrinsic values--because the impacts are short lived and reversible, and because they do not pose serious threats to the survival of species, nonuse values may not be significant.

Examples: The following examples are described in U.S. Environmental Protection Agency (1980); Kernersville, North Carolina, Reservoir (page 27); and Byron, Illinois (page 81).

III. TYPES OF ECOLOGICAL AND INTRINSIC BENEFITS

Before the empirical measurement of ecological benefits, some attention must be given to defining and measuring the relevant attributes of the ecological system. Practical questions include: is a single attribute measure sufficient or must the ecosystem be described by a vector of characteristics; can the relevant attributes be represented adequately by dichotomous measures or are scalar or continuous measures required? But for dealing with the conceptual issues being addressed in this chapter, it is sufficient to assume that the appropriate measures of ecosystem change have been identified.

Table I shows in summary form the categories of the benefits of ecological change which I propose to use in this chapter. This classification scheme has been adapted from Desvousges, Smith, and McGivney (1983). The first major distinction reflected in this table is that between production or market values and what I choose to call individual values. Production or market values arise in those cases where some attribute of the ecosystem is an argument in the production and cost functions for a marketed good. A beneficial ecological change is reflected in an increase in the economic productivity of the ecosystem and a reduction in the cost of producing the marketed good. This in turn results in changes in marketed quantities, product prices, factor prices, rents, and/or profits. Standard economic models can be used to derive measures of benefits from these market changes. See Freeman (forthcoming) for a review of these models. An interesting effort to measure the economic contribution of wetlands to the commercial blue crab fishery on the Gulf Coast can be found in Lynne, Conroy, and Prochoska (1981). While the empirical measurement of production or market values places a major burden on our knowledge of ecological relationships, the economic models for making use of this knowledge are well developed. Production and market values

Table 1

CATEGORIES OF ECOLOGICAL BENEFITS

I. Production/Market Values: Some attribute of the ecosystem is an argument in the production and cost function for a marketed good, e.g., forest products, commercial fisheries.

II. Individual Values: Some attribute of the ecosystem is an argument in individuals' utility functions.

A. Use Values - based on in situ use of the ecosystem.

B. Non-use/Intrinsic Values.

1. Existence values - unrelated to present or future uses by the individual.

2. Option values - related to uncertainty of future use and/or supply.

will not be given further consideration in this chapter.

In the case of production and market values ecological changes affect individuals only by changing the prices of goods they purchase or their incomes. In contrast, in the case of individual values some attribute of the ecosystem enters directly as an argument in the individual's utility function. Within the category of individual values, the major distinction is between those values associated with the direct or *in situ* use of the ecosystem and nonuse or intrinstic values.

The *in situ* use of an ecological system is an activity that absorbs the scarce resources of the individual, including but not limited to time. For example, the individual may have to incur time and other costs to travel to the site of the ecosystem to engage in some activity. Under some circumstances it is possible to use information on the observed behavior associated with the use of the ecosystem, such as travel cost, to infer the individual's demand for the services of the ecosystem, thus providing a basis for inferring values. The key here is the link between observable activities, that is, use of the ecosystem, and economic value. In contrast, this link is not present in the case of nonuse or intrinsic benefits. Nonuse or intrinsic values are defined as those benefits or welfare gains to individuals that arise from ecosystem changes independently of any direct use of the ecosystem. I prefer the term 'nonuse' to the more common 'nonuser' since I will show in the next section that it is possible for a user to realize additional nonuse or intrinsic benefits over and above those associated with his direct use of the ecosystem.

Since use values arise from in situ use of the ecosystem, in principle it is possible to exclude individuals from using the ecosystem and experiencing those benefits. Thus one can contemplate the emergence of markets for those environmental services generating use values if property rights were defined and transactions costs were low. In contrast, exclusion is not possible for nonuse or intrinsic values. These values are public goods; and markets cannot be relied upon to provide the optimal quantity of intrinsic values.

The category of intrinsic values can be further divided into pure existence values and option values related to uncertainty concerning future demand and/or availability of the ecosystem for possible use. The concept of pure existence value was apparently first suggested by Krutilla (1967) and was further discussed in Krutilla and Fisher (1975, p. 124). The possible motivations or rationales for existence values (for example, bequest, preservation, or other altruistic motives) will be discussed in the next section.

Weisbrod first introduced the term 'option value' into the literature of benefit cost analysis twenty years ago (Weisbrod, 1964). He argued that an individual who was unsure of whether he would visit a site such as a national park would be willing to pay a sum in excess of his expected consumer surplus to guarantee that the site would be available should he wish to visit it. Option value was said to arise when an individual was uncertain as to whether he would demand a good in some future period and was faced with uncertainty as to the supply or future availability of that good. If option price is defined as the maximum sum the individual would be willing to pay to preserve the option to visit the site before his own demand uncertainty was resolved, then the excess of option price over expected consumer surplus can be called option value. Option value is distinct from a use value in that it arises not from the use of the site itself, but from uncertainty over the site's availability or existence to meet possible future demands. Weisbrod apparently viewed the existence of positive option value as being intuitively obvious. But as subsequent analysis has shown, option value can either be positive or negative depending upon the particular circumstances.[1]

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[1]A key paper is by Schmalensee (1972). Bishop (1982) has provided a useful review and extension of the literature since Weisbrod's paper.

The questions of the relationship between option value (whether positive or negative) and use values and of the proper role of option value in welfare analysis will be taken up in section V.

IV. EXISTENCE AND USE VALUES WITH CERTAINTY

In this section I take up several questions concerning the relationship between use and existence values and possible motivations for existence value, in all cases under the assumption of certainty of future preferences, income, etc. Let us assume that an individual derives utility from the consumption of a vector of private goods, X, the number of visits to some recreation site, V, and some measure of the quality of the ecological system at the site, Q. In this general formulation, Q can be taken to be a scalar measure of some critial characteristic, for example, the population or biomass of some important species or the number of different plant or animal species present in the ecosystem.[2]

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[2]Alternatively, Q could be interpreted as a dichotomous variable taking the value Q_1 in the absence of some critical and ecological attribute and the value $Q_2 (> Q_1)$ when that attribute is present. In the latter case, the marginal utility of Q is assumed to be positive in the interval $Q_1 - Q_2$ and 0 otherwise.

Assume that the individual maximizes utility subject to the budget constraint $M - P \cdot X - F \cdot V = 0$, where P is vector of goods prices and F is the monetary cost of a visit to the site (out of pocket travel cost and entry fee, if any). The solution to this maximization problem yields a set of demand functions for X and V. In the absence of further restrictions on the form of this utility function, the demand function for V can be written as:

$$V = V(P, F, M, Q)$$

The minimum expenditure necessary to attain any given level of utility is:

$$E = E(P, F, Q, U)$$

If U^* is the solution to the utility maximization problem given P, F, M, and Q, then the compensating surplus measure of the benefit of an increase in Q from Q_1 to Q_2 is

$$S = E(P, F, Q_1, U^{\star}) - E(P, F, Q_2, U^{\star})$$

$$= \int_{Q_1}^{Q_2} - \partial E/\partial Q \cdot dQ$$

In this general formulation S could be a pure use value, a pure nonuse or existence value, or some combination of the two. If the conditions defining Mäler's weak complementarity hold, then S is a pure use value (Mäler, 1974). Two conditions on the utility and demand functions must be satisfied in order to fit Maler's definition of weak complementarity. First there must be a price for visits, $F^{\star}$, such that

$$V = V(P, F^{\star}, M, Q) = 0$$

And second at that price, the marginal utility or marginal welfare of changes in Q must be zero, that is:

$$\partial E(P, F^{\star}, Q, U^{\star})/\partial Q = 0$$

or

$$\partial U(X, O, Q)/\partial Q = 0$$

As is now well known, the conditions defining weak complementarity also allow this pure use value for changes in Q to be estimated by appropriate analysis of the demand function for V. Specifically S is equal to the area between the compensated demand curves for V for V when Q increases from Q_1 to Q_2.[3] That is:

[3]For elaboration, see Maler (1974), pp. 183-189, or Freeman (1979), pp. 72-75.

$$S = \int_{F}^{F^{\star}} V^{\star}(P, F, U^{\star}, Q_2)dF - \int_{F}^{F^{\star}} V^{\star}(P, F, U^{\star}, Q_1)dF$$

where $V^{\star}(\cdot) = \partial E/\partial F$ is the compensated demand function for V. Following the analysis of Willig (1976) and Randall and Stoll (1980), S can be approximated by the area between the ordinary demand functions for V at the two levels of Q.

Pure existence value occurs when $V = 0$ but $\partial U/\partial Q > 0$. The necessary and sufficient condition for pure existence value to arise is that the utility function be strongly separable in Q. One consequence of strong separability of the utility function is that changes in Q have no effect on market behavior; and thus there is no basis for estimating pure existence values from observations of changes in market prices or quantities.

Some authors have questioned whether a pure existence value which is independent of any type of use of the site is plausible. In justification for pure existence value, Krutilla suggested that, "An option demand may exist, therefore, not only among persons currently and perspectively active in the market for the object of the demand, but among others who place a value on the mere existence of biological and/or geomorphological variety and its widespread distribution (Krutilla, 1967, p. 781)." In an accompanying footnote, he also suggested "The phenomenon discussed may have an exclusive sentimental basis, but if we consider the bequest motivation in economic behavior, discussed below, it may be explained by an interest in preserving an option for one's heirs to view or use the object in question (Krutilla, 1967, p. 781n)." Krutilla and Fisher said,

"Perhaps closely associated with option value is the value some individuals derive from the knowledge of the existence of unspoiled wilderness, wild and scenic rivers, and related phenomena of peculiarly remarkable quality. ...In the case of existence value, we conceived of individuals valuing an environment regardless of the fact that they feel certain they will never demand in situ the services it provides...however, if we acknowledge that a bequest motivation operates in individual utility-maximizing behavior..., the existence value may be simply the value of preserving a peculiarly remarkable environment for benefit of heirs (Krutilla and Fisher, 1975, 124, references omitted).'

While Krutilla and Fisher offer a bequest motivation as one of several possible explanations for a pure existence value, McConnell takes a different point of view. He argues

'The notion that a good is valued only for its existence, that it provides no in situ services, is far fetched. In most cases, resources are valued for their use. Existence value occurs only insofar as bequest or altruistic notions prevail. We want resources there because they are valued by others of our own generation or by our heirs. Thus use value is the ultimate goal of preferences that yield existence demand, though the existence and use may be experienced by different individuals (McConnell, 1983, p. 258).'

In contrast to McConnell's view, Randall and Stoll recognize that people might experience other than altruistically motivated benefits from the existence of a site without visiting the site. However, they argue that all such non in situ uses are associated with some aspect of market related behavior thus these values constitute a form of use that they label 'vicarious consumption.' For example, 'Thus, we consider the values generated by reading about Q in a book or magazine, looking at it in photographic representations, for example, to be use values. Clearly our definition of use includes vicarious consumption (Randall and Stoll, 1983, p. 267).' In terms of our model, they view Q as enhancing the utility of elements of X.

Neither McConnell nor Randall and Stoll recognize concern for the existence of a species out of ethical considerations as a possible motive for pure existence values. While ethical philosophers are not in agreement as to the validity and proper form of such concern[4] it is possible that some people hold such values

[4]For discussions of these issues, see, for example, Norton (1982), Sagoff (1980), and Rescher (1980); pp. 79-92.

and are willing to commit resources on that basis.

This discussion of the possible motivations for pure existence value is inconclusive. I believe that this is at least in part because some of the arguments of the authors cited are misdirected in at least two respects. The first concerns various definitions of existence value. Definitions can be considered in part a matter of taste. A set of definitions can be considered useful if it furthers the research objectives and leads to useful answers to meaningful questions. If use values are limited by definition to those associated with in situ uses, these definitions have the virtue of distinguishing between those cases where use of a site generates observable data which can be used for measurement from those cases in which no meaningful data can be obtained from observing market transactions. Where vicarious uses involve information conveyed by photographs and so forth, the public good dimension of information seems likely to virtually destroy any meaningful relationship between observed market behavior and underlying values.

The second respect in which the preceding arguments may be misdirected has to do with the role of possible existence values in policy analysis. We are concerned with the question of existence values because if they are of significant size and if they are unmeasured and therefore omitted from benefit cost calculations, resource misallocations will result. The arguments about motivations for existence values seem to be offered for the primary purpose of persuading the reader that the hypothesis that existence values are positive is plausible. But the real test of this hypothesis will come from the data. Thus, rather than further debating definitions and possible motivations, the most useful step would be to proceed to a test of the hypothesis that existence values (defined in a way to make testing of the hypothesis feasible) are positive. If the evidence supports this hypothesis, then further research efforts might be devoted to testing hypotheses about the determinants (motivations) or the size of existence values in different cases.

So far I have considered two polar cases in which value accrues to individuals only through use (weak complementarity) and value is entirely independent of use (pure existence value). Now I take up the intermediate case where value accrues through use but the conditions defining weak complementarity do not hold. Using the model of preferences developed in this section, I will define the total benefit of a change in Q, use benefit, and nonuse or existence benefit. I will show that the total benefit of a change in Q is equal to the sum of the use benefit and existence benefit. Finally I will consider the problems of measuring total benefit and its components by various techniques.

As before, the benefit of a change in Q is the decrease in expenditure necessary to maintain the original utility level, U^*, or:

$$(1) \qquad S \equiv E(P, \bar{F}, Q_1, U^*) - E(P, \bar{F}, Q_2, U^*)$$

If the expenditure function is known, it can be differentiated with respect to Q to obtain the compensated inverse demand function or marginal willingness-to-pay function for Q. The benefit of a change in Q is given by the area under this marginal willingness-to-pay function between the original and final level of Q. That is,

$$S = \int_{Q_1}^{Q_2} - \partial E/\partial Q \cdot dQ$$

The use value of the site being visited is the increase in expenditure necessary to compensate for an increase in the price of a visit sufficient to reduce the number of visits to zero. The use value of an increase in Q is the increase in the use value of the site, or:

$$(2) \qquad S_U \equiv E(P, F^*, Q_2, U^*) - E(P, F_1, Q_2, U^*)$$

$$- E(P, F^*, Q_1, U^*) + E(P, F_1, Q_1, U^*)$$

where F^* is the price at which $V = 0$, and F_1 is the original price per visit. Notice that S_U can only be defined if there is the price which chokes off demand. S_U can also be measured by the area between the compensated demand curves for V at the two levels of Q, or

$$S_U = \int_{F_1}^{F^*} V^*(P, F, Q_2, U^*)dF -$$

$$\int_{F_1}^{F^*} V^*(P, F, Q_1, U^*)dF$$

where $V^*(\cdot) = \partial E/\partial F$ is the compensated demand function for visits.

Now let us define nonuse or existence benefits as that change in expenditure which holds total utility constant given that the price of visits is so high as to eliminate use of the site. In terms of the expenditure function, existence benefits, S_E are defined as follows:

$$(3) \qquad S_E \equiv E(P, F^*, Q_1, U^*) - E(P, F^*, Q_2, U^*)$$

According to this definition, existence benefits can be positive for potential users and even for those who do use the site when F is less than F^*.

The next step is to show that given the definitions employed here, an individual's total benefit from a change in Q is equal to the sum of that individual's use benefits and nonuse or existence benefit. In other words, we wish to establish that:

$$S = S_U + S_E$$

Substituting equations (2) and (3) into (1) gives:[5]

[5]This proof is similar to that given by McConnell, (1983), pp. 258-261.

$$E(P,\ F_1,\ Q_1,\ U^*) - E(P,\ F_1,\ Q_2,\ U^*)$$

$$= E(P,\ F^*,\ Q_2,\ U^*) - E(P,\ F_1,\ Q_2,\ U^*)$$

$$- E(P,\ F^*,\ Q_1,\ U^*) + E(P,\ F_1,\ Q_1,\ U^*)$$

$$+ E(P,\ F^*,\ Q_1,\ U^*) - E(P,\ F^*,\ Q_2,\ U^*)$$

All terms cancel, proving the case.

What does this analysis imply about the measurement of existence value? The first implication is that existence value and use value can only be meaningfully distinguished in those cases in which there is some price (F^*) above which use drops to zero. The definition of total benefits in equation (1) imposes no such restriction on preferences. But the definitions of both use and existence values are predicated on the existence of some price at which use falls to zero. Mäler's definition of weak complementarity is equivalent to saying that nonuse values are zero. And if the present price of the visit is equal to or greater than F^*, then use value is zero while existence value may be positive. But even 'nonusers' might become users if the price of a visit were to fall below F^*.

Second, as Mäler has shown, even if a complete system of demand functions are for X and V has been estimated on the basis of market data, the expenditure function cannot be recovered unless the conditions for weak complementarity hold. (Maler, 1974, pp. 121-125, 183-189). But positive existence value implies the violation of the weak complementarity conditions. Thus if existence value is positive, the total value of a change in Q cannot be estimated from observations of market data. It appears that contingent valuation techniques must be relied upon in this case.

The third implication concerns the measurement of use value. The accurate measurement of use value requires knowledge of the compensated demand function for visits. But this demand function cannot be recovered from market data unless the conditions for weak complementarity hold, that is, unless existence value is zero. However, as mentioned above, use value can be measured to a reasonable approximation through the use of the ordinary demand functions for visits.

What can be said about measuring S_E for users? One approach would be to use contingent valuation techniques to estimate total values for a set of users and use market techniques such as the travel cost model to estimate S_U for the same group. A comparison of the estimates of S and S_U would constitute a test of the hypothesis that existence values are positive for users. Another approach is to ask people their willingness to pay for an improvement in Q or to preserve an ecological site of given Q even if they knew they would never be able to visit the site. This is the approach taken by Desvousges, Smith, and McGivney (1983) to estimate existence values for water quality in the Monongahela River. One problem with this approach is that it asks people to place themselves in a counterfactual situation. It might be helpful to provide an explanation as to why they should imagine that they would not be able to visit the site. For example, they might be told that the price of visits had been increased to some very high number, effectively choking off demand for visits. Or they might be told that all visits had been banned to prevent damage to some fragile component of the ecosystem.

Finally, individuals might be asked a question to reveal their total value and then asked to allocate this total between use and nonuse values.[6] One problem with this approach is that

[6] Desvousges, Smith, and McGivney (1983) asked people to allocate a total willingness-to-pay or option price between user values and option values.

respondents are given no guidance as to what conditions to assume when they perform the allocation. Since nothing is said in this sort of question about the assumed price of visits, there is no reason to believe that the respondent's mental processes will reproduce the conditions defining existence value in equation (3) above.

V. UNCERTAINTY AND OPTION VALUES

In the preceding section we assumed that there was no uncertainty concerning the existence or supply of the ecological services in question; and we assumed that there was no uncertainty concerning the variables affecting an individual's demand for or value of those services. In this section we introduce uncertainty explicitly and examine its implications for the valuation of ecological services and measures of welfare change.

This uncertainty can take two forms. The first concerns uncertainty with respect to the existence or supply of the environmental service. In the preceding section we assumed that in the absence of the regulation, the level of the environmental service was known with certainty to be Q_1. The regulatory program had the certain outcome of increasing the level of environmental services to Q_2. With uncertainty in supply, there may be a nonzero probability that the higher level of environmental services (Q_2) will be supplied even in the absence of the program. The program serves to increase the probability of attaining Q_2; but it need not increase this probability to one. In other words, the program may reduce the uncertainty of supply; but it need not eliminate that uncertainty.

Another way to put it is that the program in question serves to increase the probability of a favorable outcome (Q_2) while reducing the probability of an unfavorable outcome (Q_1). In this respect, the analysis of this section parallels Smith and Desvousges' (1983) analysis of the valuation of a reduction in the risk of an unfavorable outcome.

The second form of uncertainty is uncertainty concerning the demand for or value attached to an increase in Q. A person could be uncertain concerning his demand for Q due to uncertainty concerning his income, uncertainty concerning the prices of complement or substitute goods, or uncertainty concerning his own preferences. In the simplest case, this uncertainty can be modeled as entailing some probability that the determinants of demand will take values such that the demand for Q or the value placed on Q will be zero.

As was discussed in section III, the uncertain demander was the focus of attention for those people developing the theory of option value. For the earliest writers (Weisbrod, 1966; Cicchetti and Freeman, 1971) it seemed plausible that the uncertain demander would be willing to pay a little extra now over and above his expected use value (the expected value of consumer surplus) to assure that the environmental services would be available if it should turn out that his demand were positive. The maximum payment by the individual was assumed to be independent of the state of nature, that is, it was made before the resolution of uncertainty. This state independent payment was termed option price (Cicchetti and Freeman, 1971), the presumed excess of option price over expected consumer surplus was termed option value. Option value was deemed to be a nonuse value because it was independent of any actual use of the environmental service.

Unfortunately there are two problems with this analysis. First, as is now well known, option value (or more accurately the algebraic difference between the maximum state independent payment and expected consumer surplus) could be either positive or negative (Schmalensee, 1972; Bishop, 1982). The second problem is that the maximum state independent payment (option price) may not be the appropriate measure of welfare gain associated with the provision of the environmental service. The choice of option price as the welfare measure requires specific assumptions about the nature of the underlying social welfare function or social choice criterion and about the opportunities available to the individual for diversifying risk. If these assumptions are not satisfied, then option price is not the appropriate indicator of a welfare gain.

I turn now to an examination of the issues surrounding the choice of option price as a welfare measure. I will then consider the relationship between option price and expected consumer surplus under different conditions of uncertainty. I will treat the cases of pure demand uncertainty (classical option value) and supply uncertainty for the certain demander as special cases. These questions are of importance in applied welfare analysis since measures of the consumer surpluses of actual users are frequently the only data available, while option price or some other contingent payment scheme may be the desired welfare measure. Thus the relationship between expected surluses and option prices or other contingent payment schemes may be of considerable practical importance.

Welfare Measures

An important issue in applied welfare economics and benefit cost analysis under uncertainty is the question of whether to use an ex ante or ex post welfare measure. The expected value of consumer surplus is an ex post measure in that it focuses on the realized outcomes of policy choices. Expected utility which may reflect risk aversion is the basis for ex ante welfare measurement. Option price is an ex ante measure since it is defined as that state independent payment that makes the expected utility with the project just equal to the expected utility without the project.

An ex ante social welfare function makes social welfare a function of the expected utilities of the individuals in the society while an ex post social welfare function makes social welfare equal to the expected value of the social welfares realized in alternative states of nature. The choice of an ex ante versus ex post welfare measure involves fundamental questions of welfare theory, in particular the role of equity in social welfare and the way equity is defined.[7] This is illustrated by

[7]Ulph (1982) discusses some of these questions in the context of the social value of life saving.

the fact that there is one social welfare function, the welfare weighted utilitarian or additive function which is consistent with both ex ante and ex post view of social welfare. This function can be written as

$$W = \sum_i a_i EU_i = \sum_i a_i \sum_j p_j U_{ij}$$
$$= \sum_j p_j \sum_i a_i U_{ij}$$

where i indexes individuals, j indexes states of nature, a_i are the welfare weights on the utilities of individuals, and p_j are the probabilities of alternative states of nature. Broadly speaking ex ante social welfare functions reflect a social concern with equity in opportunity in the expected value sense, while ex post social welfare functions reflect a concern with equity in outcomes.

It is not my purpose in this short discussion to settle the question of ex ante versus ex post social welfare functions. Indeed Ulph (1982) presents an example in which neither ex ante nor ex post social welfare functions appear to capture adequately some plausible equity concerns. Rather given the predominance of expected utility based welfare measures in the literature, I wish only to suggest one situation in which an ex post welfare measure with its concern with consumer surpluses might be a better measure of social preferences.

Consider a society that has adopted a social welfare function reflecting its ethical judgments concerning equity and has undertaken the necessary redistributions of wealth and/or taxes and transfer payments so as to achieve a social welfare maximum at some given point in time. Suppose a new investment opportunity is being considered which would alter the distribution of incomes and utilities in different ways and various states of nature. If the project is undertaken, then society will wish to levy taxes and make compensating payments in order to restore the optimum distribution of outcomes after the state of nature has been revealed. The consumer surplus changes provide a basis for determining the required taxes and compensation and the expected value of aggregate consumer surplus is an indicator of whether the payments can be made without making anyone worse off.

Now let us assume that society has chosen an ex ante social welfare function. Thus the focus of attention for benefit cost analysis is changes in expected utilities and their monetary equivalents. How are these monetary equivalents to be measured? Option price is only one of many possible ways of defining a monetary equivalent to a change in expected surplus. I will show that the appropriate way of defining the monetary equivalent depends upon the particular circumstances, including the opportunities for diversifying risks through contingent claims markets and the institutional feasibility of enforcing alternative contingent payment schemes.

Consider an individual who faces a given set of prices and receives income, Y, with certainty. Assume that the individual's utility is a function of the consumption of market goods and either the use of or existence of an ecological resource denoted by Q. Thus the individual's indirect utility function can be resource is available in diminished quantity or quality denoted by Q_1 with probability p_1. In the extreme, Q_1 could be zero. But there is probability p_2 (= $1 - p_1$) that the resource will be available with quality denoted by Q_2 (> Q_1). The individual's expected utility, E_N is given by:

$$E_N = p_1 \, U(Y, Q_1) + p_2 \, U(Y, Q_2)$$

Now consider an environmental regulation that would reduce the risk of harm to the resource (from p_1 to q_1) or, equivalently, increase the probability of experiencing q_2 from p_2 to q_2.

Option price (OP) is that state independent payment that makes expected utility with the regulation equal to E_N, that is, that satisfies

$$E_N = q_1 \, U(Y - OP, Q_1) + q_2 \, U(Y - OP, Q_2)$$

But there is an infinite number of alternative contingent payment schemes calling for C_i (i = i, 2) that satisfy:

(4) $$E_N = q_1 \, U(Y - C_1, Q_1) + q_2 \, U(Y - C_2, Q_2)$$

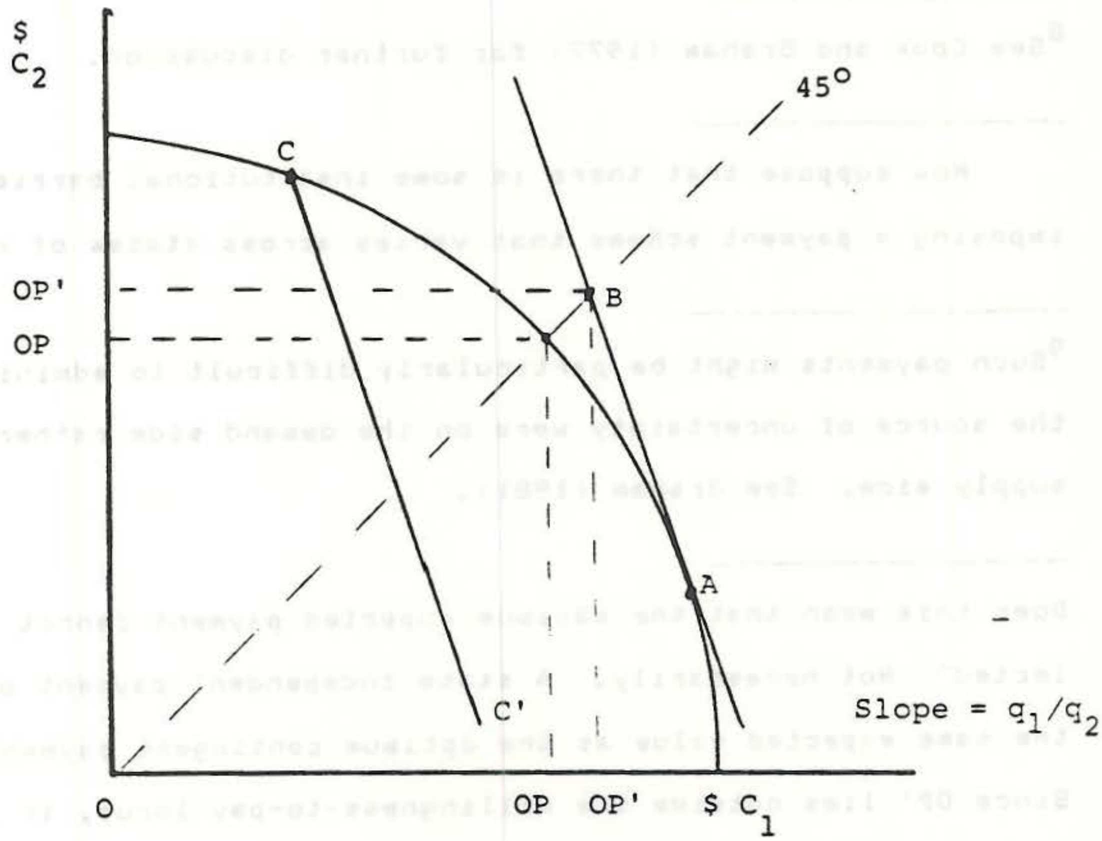
This equation defines Graham's (1981) willingness to pay locus. See Figure 1. $OP = C_1 = C_2$ is a special case. By total differentiation of (4) the slope of the willingness to pay locus is:

$$\frac{dC_2}{dC_1} = - \frac{q_1}{q_2} \frac{\partial U(Y - C_1, Q_1)/\partial Y}{\partial U(Y - C_2, Q_2)/\partial Y}$$

If the individual is risk averse, then $\partial^2/\partial y^2 < 0$ and the willingness-to-pay locus is concave to the origin.There is a family of iso-expected-payment lines with slopes of $- q_1/q_2$. One such line is tangent to the willingness-to-pay locus at point A in Figure 1. Point A represents that state dependent payment scheme which maximizes the expected value of the individual's payments. If the means exist to establish this payment scheme, then this expected payment is the appropriate money measure of the increase in expected utility associated with the regulation.The tangency of the willingness-to-pay locus and iso-expected payment line at point A implies that the marginal utilities of income are equal in the two states. This equality is the condition for the efficient distribution of risk or for the optimum purchase of contingent claims at actuarially fair prices. In this sense, point A represents an optimum contingent payment scheme and in Graham's (1981) terminology in the fair bet point. Alternatively suppose the individual were required to make those contingent payments representated by point C in Figure 1. If the individual is able to purchase contingent claims at fair prices represented by q_1/q_2, he would use these claims to move to point C' inside the willingness-to-pay locus, thereby achieving a higher level of expected utility.

It is interesting to note that as drawn in Figure 1, the optimum contingent payment plan involves a larger payment in state 1 when the ecological resource is degraded. This would be the case if an increase in Q increased the marginal utility of income, other things equal. This is equivalent to saying the price flexibility of income for Q is greater than zero. When Q is degraded

Figure 1



in state 1, the marginal utility of income is lower, other things equal. Thus the optimal contingent payment plan involves a larger payment with lower marginal utility of income dollars in state 1.[8]

[8]See Cook and Graham (1977) for further discussion.

Now suppose that there is some institutional barrier to imposing a payment scheme that varies across states of nature.[9]

[9]Such payments might be particularly difficult to administer if the source of uncertainty were on the demand side rather than the supply side. See Graham (1981).

Does this mean that the maximum expected payment cannot be collected? Not necessarily. A state independent payment of OP′ has the same expected value as the optimum contingent payment scheme. Since OP′ lies outside the willingness-to-pay locus, it would appear to leave the individual worse off, that is, with a lower expected utility. However, if the individual can buy contingent claims at actuarially fair prices, he can alter his risk position to reach point A. Thus the availability of actuarially fair insurance makes the maximum expected payment feasible even when varying payments across states of nature are not possible.

However if the risk of ecological loss is a collective risk, then private contingent claims markets cannot exist. The absence of a contingent claims market combined with a bar to nonuniform contingent payment plans makes OP the maximum feasible expected payment. Thus in this 'second best' world, option price is the money equivalent of the increase in expected utility.[10]

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[10]See also Graham (1981).

Smith and Desvousges (1983) have also analyzed the value of changes in the probabilities of adverse and favorable outcomes. Although their framework for analysis is somewhat different, our results are consistent. They assume the existence of fair contingent claims markets and define the measure of welfare change to be the change in endowment or expected wealth that keeps expected utility constant. They consider the impact of the availability of insurance at other than fair prices. But they do not explicitly take up the 'second best' case of no contingent claims market and a constraint that payments be equal across states of nature.

In conclusion if social welfare is a function of expected utilities, the money equivalent of a change in expected utility for an individual is the maximum <u>feasible</u> expected payment that can be extracted from that individual without reducing his expected utility. If any contingent payment plan is feasible or if contingent claims are available at fair prices, then the maximum expected payment corresponds to Graham's 'fair bet' point and represents an optimum distribution of contingent payments across states of nature. However in the second best world of no contingent claims markets and barriers to unequal contingent claims plans, the maximum feasible expected payment is option price. In any event option price is a lower bound estimate of the true maximum expected payment.

I now turn to a consideration of the relationship between option price and expected consumer surplus for the individual. This relationship may be important if ex post social welfare considerations are relevant. Also if option price is the desired or "second best" welfare measure, it may be that the only available data on values are the consumer surpluses of those actually using the ecological resource.

Sources of Uncertainty

In this section I develop a model for analyzing the relationship between option price and expected consumer surplus under various conditions of both demand and supply uncertainty. Consider an individual who is uncertain concerning his demand for a good and who is also confronted with uncertain supply. Option price is the maximum sure payment the individual would make for a program to reduce or eliminate the supply uncertainty on the understanding that if the payment is not made the individual would be excluded from the benefits of the increase in the probability of supply. Option value is the difference between this maximum willingness to pay and the increase in expected consumer surplus with the program.

Let the program in question be a set of regulations which reduces the risk of the adverse ecological consequences of a hazardous waste spill. If there is no spill, the individual can make use of the services of the ecological resource at zero price. But the occurrence of a spill precludes the use of the ecological resource. The individual's indirect utility function takes the form:

(4) $U = U(Y,P,Q)$

where Q represents the availability of the ecological resource:

$Q = Q_2 \equiv$ the resource is available.

$Q = Q_1 \equiv$ the resource is not available.

Y is income, and P is a vector of prices including the prices of substitute and complement goods for Q. The option value literature has focused on the behavior of risk averse individuals. So let us assume risk aversion, that is:

$$\frac{\partial^2 U}{\partial Y^2} < 0$$

Demand uncertainty can arise because of uncertainty about income, uncertainty about the prices of complement or substitute goods, or uncertainty about preferences. At this point in the argument, it is not necessary to be more specific about the nature of demand uncertainty. Assume for simplicity that there are only two possible outcomes with respect to demand for the resource. (1) The demand is zero with probability p_1. The utility function can be written as

$$U_{ND}(Y_{ND}, P_{ND})$$

where the subscripts indicate that preferences, incomes and/or prices take values such that the park is not demanded. (2) The demand is positive with probability p_2 leading to

$$U_D(YD, PD, Q)$$

Furthermore:

$$U_D(Y_D, P_D, Q_2) > U_D(Y_D, P_D, Q_1)$$

But if the demand for the resource is zero (for example because of low income or high prices of complements), the individual is indifferent as to its availability. This assumption rules out such things as preservation, existence, or bequest values.

For any given set of demand conditions, the compensating surplus measure of the value of the opportunity to use the resource is given by

(5) $$U_i(Y_i - S_i, P_i, Q_2) = U_i(Y_i, P_i, Q_1)$$

where i = D, ND. So from the above assumptions, it follows that

$$S_D > 0 \text{ and } S_{ND} = 0.$$

In the subsequent notation S will represent positive surpluses associated with demanding the service.

Now to introduce uncertainty of supply, let $q_1 > 0$ be the probability that the resource will not be available in the absence of the investment project. So even without the program there is a probability of $q_2 = q_1 - q_1 > 0$ that the resource will be available. This represents an extension of the standard option value models from Weisbrod (1964) to Freeman (1984) which assumed that if the option price were not paid the individual would have no chance to use the resource.

If the individual demands the resource, and if it is available at a zero price, the individual is better off by S. In the absence of the program to reduce supply uncertainty, expected utility is:

$$(6) \qquad EN = p_1 U_{ND}(Y_{ND}, P_{ND}) + q_1 p_2 U_D(Y_D, P_D, Q_1) + q_2 p_2 U_D(Y_D, PD, Q_2)$$

and expected consumer surplus is $q_2 p_2 S$.

Consider now a program which would reduce supply uncertainty. Suppose that with the program the probability of supply is $r_2 (q_2 < r_2 \leq 1)$. Expected consumer surplus with the program is $r_2 p_2 S$; and the program increases expected consumer surplus by $(r_2 - q_2) p_2 S$. The question posed in the option value literature is whether there is a willingness to pay for the program over and above the increase in expected consumer surplus. Option price is that state independent payment which makes expected utility with the program (E_0) equal to E_N, where

$$(7) \qquad E_0 = p_1 U_{ND}(Y_{ND} - OP, P_{ND}) + r_1 p_2 U_D(Y_D - OP, P_D, Q_1) + r_{2p} U_D(Y_D - OP, P_D, Q_2)$$

What can be said about the sign of $OV = OP - (r_2 - q_2) p_2 S$? It should be no surprise that the answer is, "it depends." It depends on the degree of the individual's risk aversion, the nature and source of demand uncertainty, and the nature of supply uncertainty, as well as on the interactions between demand and supply uncertainty. To sort out these factors, I will first briefly describe some results for the standard model of demand uncertainty with supply uncertainty assumed away, i.e., $q_1 = 1$, $r_2 = 1$. I will then present some new results for the case of supply uncertainty with certain demand.

In a recent paper, Hartman and Plummer (unpublished) presented a rigorous, mathematical analysis of the cases where demand uncertainty arises from uncertainty about income or about the prices of substitute or complement goods for a risk averse individual. In another paper (Freeman, 1984) I used Graham's (1981) graphical model to generalize some of these results to other attitudes towards risk and to investigate some classes of state dependent preferences. In all of these cases, the key determinant of the sign of option value is the relationship between the marginal utilities of income in the two states of the world: the good is demanded, and the good is not demanded.

The key feature of Graham's model is the willingness to pay locus. One point on the locus is given by the payment of OP in both states of the world. A second point is where a payment of S is required if the resource is demanded; but the payment is zero if the resource is not demanded. If the marginal utility of income is higher in the state of the world in which the resource is not demanded, and if this is true regardless whether the marginal utility is evaluated at the point where S is paid only when the good is demanded or at the point corresponding to the payment of OP, then option price will be less than expected surplus and option value will be negative. The economic intuition behind this result is straightforward. If the marginal utility of income is higher in the 'no demand state', the option price scheme of payment means that there is a nonzero probability that the individual will have to make the payment of OP using high marginal utility dollars. But if payment is required only in the demand state, the individual is assured of being required to pay only with low marginal utility dollars. The prospect of perhaps having to pay with high marginal utility dollars reduces the size of the sure payment (OP) that the individual is willing to commit himself to make. This point was emphasized by Bohm (1975).

If demand uncertainty arises because the individual is uncertain of his income, then option value will be negative for the risk averse and positive for the risk preferring individual. At least if the use of the resource is a normal good, the state of the world with higher income corresponds to demanding the good; and for the risk averse individual, the marginal utility of income is lower in this state. Thus the individual will prefer to make payment only in the state of the world in which income is high and the good is demanded.

If demand uncertainty arises because of uncertainty about the price of a complement good (for example, the price of travel to the resource), option value will be positive for the risk neutral and risk preferring individual. In the state of the world where the price of the complement is low, the resource is demanded, and the purchasing power and marginal utility of a dollar of income are higher. Thus the individual would prefer the option price scheme with its chance to make payments with lower marginal utility dollars. But for the risk averse individual, the sign of option value depends on what happens to the marginal utility of income as the price of the complement changes.[11]

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[11]See Hartman and Plummer (unpublished) and Freeman (1984) for details.

Where demand uncertainty arises because of state dependent preferences, one must know something about the shapes of the alternative utility functions. But some general statements can be made. For a risk neutral individual, option value is positive when the marginal utility of income is higher in the state where the resource is demanded, and it is negative when the marginal utility of income is lower in the 'demand' state. If the marginal utilities are the same, option value is zero.

If the individual is risk averse, the sign of option value depends on both how the marginal utility of income schedules differ between the two states and how much the marginal utility of income in the demand state increases because of the payment of S. If the marginal utility of income schedule of the demand state is identical to or above that of the no demand state, option value will be positive.

Most of the authors who have discussed practical applications of the option value concept have mentioned examples in which the uncertainty about demand arises not from uncertainty concerning some state variable, e.g., weather, or scheduling of a vacation, which governs whether a trip to use the resource will be made. One plausible way to model this situation is to assume that the indirect utility function is strongly separable in income and the state variable, so that utility in state i is:

(8) $$U_i = U(Y, P, Q) + V(S_i);\ i = D, ND$$

where $\partial V/\partial D_i > 0$ and D_i is random variable with $D_{ND} = 0$, and with $D_D > 0$.[12] If D is positive and the resource is used, total utility is higher, but the marginal utility of income schedule is unchanged. With income the same in both states, the individual would prefer to make the same payment OP rather than have to pay S with higher marginal utility dollars when the resource is demanded. Therefore option value is positive.

Although there are no doubt other ways to model the behavior of the uncertain resource user, this simple model seems to capture the essence of the problem first considered by Weisbrod. And it justifies the supposition that there could be willingness to pay to reduce supply uncertainty over and above the expected value of consumer surplus, at least in those cases where the alternatives are the certain destruction of a resource or certain preservation.

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[12]Plummer (forthcoming) has shown that this implies the following condition on the direct utility function:

$$-\frac{\partial^2 U/\partial D \partial X}{\partial^2 U/\partial D \partial Y} = \frac{dY/dM}{dX/dM}$$

This has no obvious intuitive explanation.

Now let us assume that income, prices, and preferences are independent of the state of the world and that the good is demanded with certainty ($p_2 = 1$). This means that the expression defining OP given by equations (6) and (7) reduces to:

$$(9a) \qquad q_1 U(Y, Q_1) + q_2 U(Y, Q_2)$$

$$= r_1 U(Y - OP, Q_1) + r_2 U(Y - OP, Q_2)$$

or from (5):

$$(9b) \qquad q_1 U(Y - CS_D, Q_2) + q_2 U(Y, Q_2)$$

$$= r_1 U(Y - OP, Q_1) + r_2 U(Y - OP, Q_2)$$

where the price term is dropped for simplicity.

In the most general analysis, four possible cases can be distinguished on the basis of whether the option is sure ($r_2 = 1$) or unsure ($r_2 < 1$) and whether or not there is a possibility of supply in the absence of the project. These cases can be summarized as follows:

Case A: No project - No supply
With project - Sure supply $q_2 = 0$, $r_2 = 1$

Case B: No Project - Possible supply
With Project - Sure supply $q_2 > 0$, $r_2 = 1$

Case C: No Project - No supply
With Project - Possible supply $q_2 = 0$, $r_2 < 1$

Case D: No Project - Possible supply

With Project - Possible supply $0 < q_2 < r_2 < 1$

Each of these cases can be analyzed by imposing the appropriate probability conditions on equations (9a) or (9b) and solving for OP.

For Case A ($q_2 = 0$, $r_2 = 1$), equation (9b) reduces to:

$$U(Y - S, Q_2) = U(Y - OP, Q_2)$$

Therefore:

$$OP = S = (r_2 - q_2)S$$

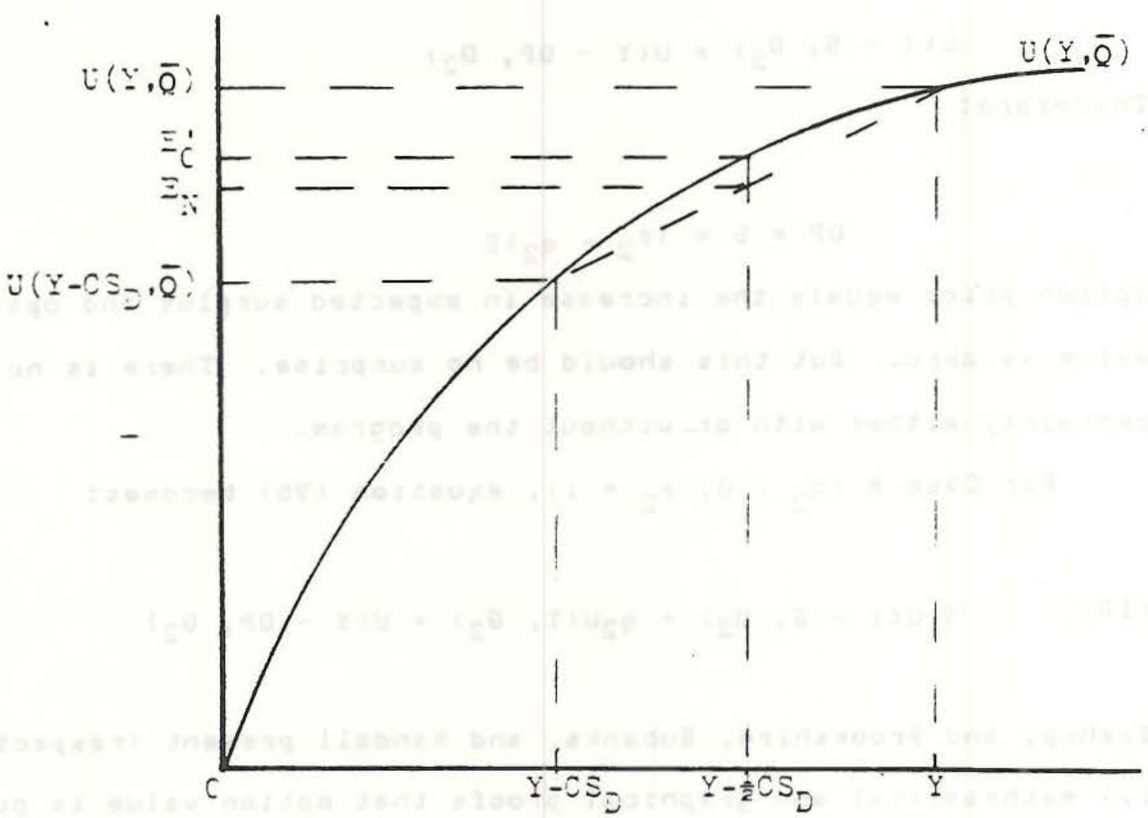
Option price equals the increase in expected surplus and option value is zero. But this should be no surprise. There is no uncertainty either with or without the program.

For Case B ($q_2 > 0$, $r_2 = 1$), equation (9b) becomes:

$$(10) \qquad q_1U(Y - S, Q_2) + q_2U(Y, Q_2) = U(Y - OP, Q_2)$$

Bishop, and Brookshire, Eubanks, and Randall present (respectively) mathematical and graphical proofs that option value is positive for risk averse individuals. A graphical proof can be presented with the aid of Figure 2 which shows utility as a function of income, given that the resource is available. Assume that $q_2 = 1/2$. The left hand side of (10) gives E_N as shown in the figure. Now suppose that with the program the individual must make a payment equal to $(r_2 - q_2)S$. The expected utility of this payment scheme is $E_0' = E_N$. The individual must be required to pay

Figure 2



an OP > 1/2S, so option value is positive. The intuition is straightforward. In the absence of the program, the individual in effect holds a lottery on Q. The risk averse individual would pay more than the expected monetary equivalent of the lottery (expected S) in order to eliminate the uncertainty associated with the lottery. This supply-side option value is a risk aversion premium.

For Case C ($q_2 = 0$, $r_2 < 1$), equation (9b) becomes:

$$(11) \qquad U(Y - S, Q_2) = r_1U(Y - OP, Q_1) + r_2U(Y - OP, Q_2)$$

In this case, the sign of option value is indeterminate. A mathematical proof requires the introduction of two new terms.[13]

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[13] I am indebted to John Fitzgerald for suggesting this proof.

Let $Y_{\star} \equiv Y - OP$ and define $S^{\star}$ by:

$$(12) \qquad U(Y^{\star} - S^{\star}, Q_2) = U(Y^{\star}, Q_1)$$

Strict concavity of U in income implies:

$$(13) \quad U[r_1(Y^{\star} - S^{\star}) + r_2Y^{\star}. Q_2] > r_1U(Y^{\star} - S^{\star}. Q_2) + r_2U(Y^{\star}. Q_2)$$

Using (11), (13), and the definitions gives:

$$U(Y - OP^{\star} - S^{\star} + r_2S^{\star}, Q_2 > U(Y - S, Q_2)$$

Thus: $-OP - S^{*} + r_2 S^{*} > -S$

or after some rearrangement:

$$(14) \qquad OP < r_2 S + (1 - r_2)(S - S^{*})$$

S is independent of income, then the second term on the right hand side of (14) drops out and option value is negative. But in the more likely case that Q is a normal good or has a positive price flexibility of income, then $S^{*} > S$. Although (14) must still hold, OP could exceed $r_2 S$ resulting in positive option value.

In Case D all of the probabilities are positive. I have not been able to find a general proof regarding the relationship between OP and $(r_2 - q_2)S$. However I have done sample numerical calculations with alternative utility functions, parameters, and probabilities and have found both positive and negative option values.[13] Thus I conclude that the sign of option value is

[13]These calculations are available from the author.

indeterminate in this case.

So far in this section I have shown that demand uncertainty and supply uncertainty have separate effects on the sign of option value and that there are at least some circumstances in which the signs of these effects can be predicted from a qualitative analysis of the problem. The question of the sign of option value when both demand and supply uncertainty are present is difficult. Option price is the solution to equations (6) and (7). It clearly depends on the pattern of supply uncertainty as reflected in q_2 and r_2, the degree of demand uncertainty as measured by p_2 and the determinants of demand uncertainty. The increase in expected surplus $p_2(r_2 - q_2)S$ also reflects both types of uncertainty. Since the signs of demand- and supply-side option value depend on specific and different properties of individuals' utility functions, it seems unlikely that any general statement can be made. It appears in the general case, the relationship between option price and the increase in expected surplus can only be determined through a quantative analysis based on knowledge of the relevant probabilities and the specific properties of the utility function[14]

[14] See Freeman (1984) for the results of such quantitative analysis for the case of demand uncertainty.

Conclusions

As the preceding analysis has shown, it is at best misleading to speak of option value as a separate category of benefits. Option value is defined as the algebraic difference between two different concepts of welfare change, the ex ante concept (the money equivalent of the change in expected utility) and the ex post concept (the change in expected consumer surplus). As such, option value can be either greater than zero or less than zero depending upon the structure of preferences and the nature of the uncertainties involved.

The theoretical analysis of option value may prove to be most useful through providing a bridge between the two different concepts of welfare change. For example in the case of demand uncertainty it may be possible to use indirect techniques such as the travel cost method to estimate the consumer surpluses of users of the resource. If observed users can be assumed to represent a random sample of all potential users, then the observed consumer surplus is an estimate of the expected consumer surplus of all uncertain demanders. Then, if the causes of demand uncertainty can be adequately characterized, it may be possible to compute option prices by making some assumption about the functional form and parameters of the von Neumann-Morgenstern indirect utility function. Similarly for the case of supply uncertainty, estimates of of consumer surpluses realized when the good is supplied may provide the basis for calculating option price.

VI. TOWARD MEASUREMENT

In this section I attempt to draw out the implications of the preceding analysis for efforts to estimate the ecological and intrinsic benefits stemming from hazardous waste regulation. In a world of uncertainty, individuals can be placed in one of three categories with respect to their possible use of the ecological resource. First, there are those who are certain to use the resource if it is available. Second, there are those who are uncertain of their use of the resource. They are potential or possible users. And third, there are those whose probability of using the resource is effectively zero, that is, they are nonusers. Of course the boundary between the second and third categories may be indistinct in practice. If we ask individuals to identify themselves as either potential users or nonusers, some people with low but nonzero probabilities of future use may identify themselves as nonusers. And statistical models for predicting probability of use may generate trivially small but nonzero probabilities for many individuals. As a practical matter they should be treated as nonusers.

The first and second categories of individuals can have both use and existence values for the resource. The third category can have only existence values.

For the moment let us assume that the probability of the supply of the resource is one. Use values for actual users (drawn from both the first and second-categories) can be estimated by existing indirect methods such as the travel cost model. But these methods are incapable of shedding any light on possible existence values.

One approach to estimating the total value for certain users is to ask them a contingent valuation question about their total willingness to pay for the resource. If respondents understand that this value is to encompass both use and existence values, then their answers are all that is needed for policy purposes. However, in order to test hypotheses about the magnitude of and determinants of existence value, it would be useful to have the total value broken down into its two components. Some researchers have simply asked people to allocate their total willingness to pay into use and existence categories. However I am distrustful of this approach. It asks people to place themselves in a hypothetical situation which may be difficult for them to imagine. that is, it asks them to imagine that they are nonusers without specifying for them the reason that they no longer use the resource. Another approach is to compare the contingent value responses with estimates of use values derived from indirect techniques. In principle, the difference between the two measures is existence value. However, in practice, at least part of the difference may be due to measurement errors in either or both measures.

For the second category, one approach is to estimate expected consumer surplus from data on actual users and to use assumptions about the structure of demand uncertainty and preferences to compute option price. But this gives an estimate of the increase in expected utility associated only with use. Again, the only way to get at existence values is to ask a contingent valuation question about total willingness to pay. And finally, for certain nonusers, contingent valuation questions are the only basis for drawing inferences about existence values.[15]

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[15]See Brookshire, Eubanks and Randall (1983) for an example in which certain nonusers in the sample were identified. Their responses were interpreted as pure existence values.

In the case of uncertainty in supply and programs to increase the probability of availability, consumer surpluses of actual users may provide a basis for estimating increases in expected use values. But as in the case of only demand uncertainty, contingent valuation questions are required to obtain total values that include existence values.

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UNCERTAINTY AND ENVIRONMENTAL POLICY: THE ROLE OF OPTION AND QUASI-OPTION VALUES

by

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"I have come to bury Caesar, not to praise him." William Shakespeare, Julius Caesar, Act III, Sc. II.

I. INTRODUCTION

There are two separate and distinct forms of uncertainty to be dealt with in the economic analysis of environmental policy. The first is that uncertainty faced by individuals who are users or potential users of an environmental resource. For example individual users of a contaminated ground water aquifer may face a higher probability of cancer. Individuals may be uncertain as to whether a particular unique and irreplacable environmental resource will be available for their use on some future date. And individuals may also be uncertain as to whether they will actually want to use some environmental resource in the future. In these cases the analytical problem is to incorporate uncertainty explicitly into the measurement of welfare changes associated with policy changes dealing with these environmental resources. The literature on option value has been concerned with some aspects of the question of the economic value of reducing this form of uncertainty.

The second form of uncertainty is that faced by a public policy maker who may be uncertain about the magnitudes of the benefits and costs of the alternative policies she is contemplating. This form of uncertainty could arise because of inadequate or incomplete scientific knowledge of the underlying physical and biological processes that influence the value of an environmental resource to people. Or it could arise from lack of information about or inaccurate measures of the economic relationships and variables governing individuals' use of the environmental resource and the value they derive from it. The literature on quasi-option value has focused on one aspect of this form of uncertainty.[1]

In this paper I review some recent results in the theoretical analysis of option value and the welfare effects of changes in uncertainty and use these results to assess the usefulness of option value as a concept in environmental policy analysis. As my epigraph suggests, I think that option value is not a particularly useful concept. Although this session is primarily about option value, I have chosen to include an assessment of the related concept of quasi-option value with essentially similar results. The next two sections of the paper are devoted to the analyses of option value and quasi-option value. The concluding section discusses some similarities between these two concepts in an effort to justify their inclusion in one paper.

II. INDIVIDUAL UNCERTAINTY AND OPTION VALUE

In this section I examine the implications of individual uncertainty for the valuation of environmental resources and measurement of changes in individual welfare. Individual uncertainty can take two forms. The first is uncertainty with respect to the existence or supply of the environmental resource. I will characterize this uncertainty as follows. Let Q be the level of the environmental resource. The individual believes that one of two alternative states of nature will prevail in the future. In state 1 the resource is available at reduced level, $Q_1 \geq 0$. In state 2 the resource is available at a higher level, $Q_2 > Q_1$. The individual attaches probabilities of q_1 and q_2 ($q_2 = 1 - q_1$) to these alternatives states of nature.

The environmental policy to be evaluated has the purpose of increasing the probability of the higher level of supply of the environmental resource. Specifically with the policy, the subjective probabilities of the two states of nature become $r_1 < q_1$ and $r_2 > q_2$. The conventional analysis of environmental policy that ignores uncertainty can be treated as a special case of this formulation in which $q_1 = 1$ and $r_2 = 1$.

The second form of individual uncertainty is uncertainty concerning the individuals' demand for or value attached to an increase in Q. A person could be uncertain concerning his demand for Q due to uncertainty concerning his income, uncertainty concerning the prices of complement or substitute goods, or uncertainty concerning his own preferences. In the simplest case, this uncertainty can be modeled as entailing some probability that the determinants of demand will take values such that the demand for Q or the value placed on Q will be zero.

The uncertain demander was the focus of attention for those people developing the theory of option value. For the earliest writers, for example, Weisbrod (1964) and Cicchetti and Freeman (1971), it seemed plausible that the uncertain demander would be willing to pay a little extra now over and above his expected use value (the expected value of consumer surplus) to assure that the environmental resource would be available if it should turn out that his demand were positive. The maximum payment by the individual was assumed to be independent of the state of nature, that is, it was made before the resolution of uncertainty. This state independent payment was termed option price (Cicchetti and Freeman, 1971); and the presumed excess of option price over expected consumer surplus was termed option value.

Unfortunately there are two problems with this analysis. First, as is now well known, option value (or more accurately the algebraic difference between the maximum state independent payment and expected consumer surplus) could be either positive or negative (Schmalensee, 1972; Bishop, 1982). The second problem is that the maximum state independent payment (option price) may not be the appropriate measure of welfare gain associated with the provision of the environmental resource. The choice of option price as the welfare measure requires specific assumptions about the nature of the underlying social welfare function or social choice criterion and about the opportunities available to the individual for diversifying risk. If these assumptions are not satisfied, then option price is not the appropriate indicator of a welfare gain.

I turn now to an examination of two issues surrounding the choice of option price as a welfare measure: the choice of an ex ante <u>vs</u>. an ex post welfare criterion; and under what conditions option price is a valid ex ante welfare measure. I will then consider the relationship between option price and expected consumer surplus under different conditions of uncertainty. I will treat the cases of pure demand uncertainty (classical option value) and supply uncertainty for the certain demander as special cases.

Welfare Measures

An important issue in benefit cost analysis under uncertainty is whether to use an ex ante or ex post welfare measure. The expected value of consumer surplus is an ex post measure in that it focuses on the realized outcomes of policy choices. Expected utility which may reflect risk aversion is the basis for ex ante welfare measurement. Option price is an ex ante measure since it is defined as that state independent payment that makes the expected utility with the project just equal to the expected utility without the project.

An ex ante social welfare function makes social welfare a function of the expected utilities of the individuals in the society while an ex post social welfare function makes social welfare equal to the expected value of the social welfares realized in alternative states of nature. The choice of an ex ante versus ex post welfare measure involves fundamental questions of welfare theory, in particular the role of equity in social welfare and the way equity is defined.[2]

Broadly speaking ex ante social welfare functions reflect a social concern with equity in opportunity in the expected value sense, while ex post social welfare functions reflect a concern with equity in outcomes. For example, consider a society that has adopted a social welfare function reflecting its ethical judgments concerning equity and has undertaken the necessary redistributions of wealth and/or taxes and transfer payments so as to achieve a social welfare maximum at some given point in time. Suppose a new investment opportunity is being considered which would alter the distribution of incomes and utilities in different ways in various states of nature. If the project is undertaken, then society will wish to levy taxes and make compensating payments in order to restore the optimum distribution of outcomes after the state of nature has been revealed. Consumer surplus changes provide a basis for determining the required taxes and compensation; and the expected value of aggregate consumer surplus is an indicator of whether the payments can be made without making anyone worse off.

However most of the literature on investment under uncertainty in environmental economics and elsewhere focuses on such things as risk aversion and ignores such things as ex post compensation, thus implying acceptance of an ex ante welfare criterion. Therefore I will assume the appropriate focus of attention for benefit cost analysis is changes in expected utilities and their monetary equivalents. How are these monetary equivalents to be measured? Option price is only one of many possible ways of defining a monetary equivalent to a change in expected utility. I will show that the appropriate way of defining the monetary equivalent depends upon the particular circumstances, including the opportunities for diversifying risks through contingent claims markets and the institutional feasibility of enforcing alternative contingent payment schemes.

Consider an individual who faces a given set of prices and receives income, Y, with certainty. Assume that the individual's utility is a function of the consumption of market goods and either the use of or existence of an environmental resource, denoted by Q. Thus the individual's indirect utility function can be written as:[3]

$$U = U(Y, Q)$$

Suppose that at present there is uncertainty as to the supply of this resource as described above. The individual's expected utility, E_N is given by:

$$E_N = q_1 \; U(Y, Q_1) + q_2 \; U(Y, Q_2)$$

Now consider an environmental regulation that would increase the probability of experiencing Q_2 from q_2 to r_2. Option price (OP) is that state independent payment that makes expected utility with the regulation (E_P) equal to E_N, thus satisfying

$$E_N = r_1 \; U(Y - OP, Q_1) + r_2 \; U(Y - OP, Q_2)$$

There is an infinite number of alternative contingent payment schemes calling for C_i $(i = 1, 2)$ that satisfy:

$$(1) \qquad E_N = r_1 U(Y - C_1, Q_1) + r_2 U(Y - C_2, Q_2)$$

This equation defines Graham's (1981) willingness to pay locus. See Figure 1. $OP = C_1 = C_2$ is a special case. By total differentiation of (1) the slope of the willingness to pay locus is:

$$\frac{dC_2}{dC_1} = - \frac{r_1}{r_2} \frac{\partial U(Y - C_1, Q_1)/\partial Y}{\partial U(Y - C_2, Q_2)/\partial Y}$$

If the individual is risk averse, then $\partial^2 U/\partial y^2 < 0$ and the willingness-to-pay locus is concave to the origin. There is a family of iso-expected-payment lines with slopes of $- r_1/r_2$. One such line is tangent to the willingness-to-pay locus at point A in Figure 1. Point A represents that state dependent payment scheme which maximizes the expected value of the individual's payments. If collection of these payments is feasible, then this expected payment is the appropriate money measure of the increase in expected utility associated with the regulation. The tangency of the willingness-to-pay locus and iso-expected payment line at point A implies that the marginal utilities of income are equal in the two states. This equality is the condition for the efficient distribution of risk or for the optimum purchase of contingent claims at actuarially fair prices. In this sense, point A represents an optimum contingent payment scheme and in Graham's (1981) terminology is the fair bet point. Alternatively suppose the individual were required to make those contingent payments representated by point C in Figure 1. If the individual is able to purchase contingent claims at fair prices represented by r_1/r_2, he would use these claims to move to point C′ inside the willingness-to-pay locus, thereby achieving a higher level of expected utility.

It is interesting to note that as drawn in Figure 1, the optimum contingent payment plan involves a larger payment in state 1 when the environmental resource is degraded. This would be the case if an increase in Q increased the marginal utility of income, other things equal. This is equivalent to saying the price flexibility of income for Q is greater than zero. When Q is degraded in state 1, the marginal utility of income is lower, other things equal. Thus the optimal contingent payment plan involves a larger payment with lower marginal utility of income dollars in state 1.[4] Now suppose that there is some institutional barrier to imposing a payment scheme that varies across states of nature.[5] Does this mean that the maximum expected payment cannot be collected? Not necessarily. A state independent payment of OP′ has the same expected value as the optimum contingent payment scheme. Since OP′ lies outside the willingness-to-pay locus, it would appear to leave the individual worse off, that is, with a lower expected utility. However, if the individual can buy contingent claims at actuarially fair prices, he can alter his risk position to reach point A. Thus the availability of fair insurance makes the maximum expected payment feasible even when varying payments across states of nature are not possible. But if the risk of ecological loss is a collective risk, then private contingent claims markets cannot exist. The absence of a contingent claims market combined with a barrier to nonuniform contingent payment plans makes OP the maximum feasible expected payment. Thus in this "second best" world, option price is the money equivalent of the increase in expected utility.[6]

In conclusion if social welfare is a function of expected utilities, the money equivalent of a change in expected utility for an individual is the maximum feasible expected payment that can be extracted from that individual without reducing his expected utility. If any contingent payment plan is feasible or if contingent claims are available at fair prices, then the maximum expected payment corresponds to Graham's "fair bet" point and represents an optimum distribution of contingent payments across states of nature. However in the second best world of no contingent claims markets and barriers to unequal contingent payment plans, the maximum feasible expected payment is option price.

Option Price and Option Value

In this section I develop a model for analyzing the relationship between option price and expected consumer surplus under various conditions of both demand and supply uncertainty. Consider an individual who is uncertain concerning his demand for a good and who is also confronted with uncertain supply. Option price is the maximum sure payment the individual would make for a program to reduce or eliminate the supply uncertainty on the understanding that if the payment is not made the individual would be excluded from the benefits of the increase in the probability of supply. Option value is the difference between this maximum willingness to pay and the increase in expected consumer surplus with the program.

Demand uncertainty can arise because of uncertainty about income, uncertainty about the prices of complement or substitute goods, or uncertainty about preferences. At this point in the argument, it is not necessary to be more specific about the nature of demand uncertainty. Assume for simplicity that there are only two possible outcomes with respect to demand for the resource. (1) The demand is zero with probability p_1 with utility given as:

$$U_{ND}(Y_{ND}, P_{ND})$$

where the subscripts indicate that preferences, incomes and/or prices take values such that the resource is not demanded. (2) The demand is positive with probability p_2 leading to:

$$U_D(Y_D, P_D, Q)$$

F

Furthermore:

$$U_D(Y_D, P_D, Q_2) > U_D(Y_D, P_D, Q_1)$$

For any given set of demand conditions, the compensating surplus measure of the value of the opportunity to use the resource is given by

$$U_i(Y_i - S_i, P_i, Q_2) = U_i(Y_i, P_i, Q_1)$$

where i = D, ND. So from the above assumptions, it follows that

$$S_D > 0 \text{ and } S_{ND} = 0.$$

The uncertain demander is also faced with uncertainty of supply as describe above. This represents an extension of the standard option value models from Weisbrod (1964) to Freeman (1984). They assumed that if the option price were not paid the individual would have no chance to use the resource, but payment of OP would guarantee its availability.

If the individual demands the resource, and if it is available at a zero price, the individual is better off by S_D. In the absence of the program to reduce supply uncertainty, expected utility is:

$$E_N = p_1U_{ND}(Y_{ND}, P_{ND}) + q_1p_2U_D(Y_D, P_D, Q_1)$$
$$+ q_2p_2U_D(Y_D, P_D, Q_2)$$

and expected consumer surplus is $q_2p_2S_D$.

Consider now a program which would increase the probability of supply. Expected consumer surplus with the program is $r_2 p_2 S_D$; and the program increases expected consumer surplus by $(r_2 - q_2)p_2 S_D$. The question posed in the option value literature is whether there is a willingness to pay for the program over and above the increase in expected consumer surplus. Option price is that state independent payment which makes expected utility with the program (E_P) equal to E_N, where

$$E_P = p_1 U_{ND}(Y_{ND} - OP, P_{ND}) + r_1 p_2 U_D(Y_D - OP, P_D, Q_1)$$

$$+ r_2 p_2 U_D(Y_D - OP, P_D, Q_2)$$

What can be said about the sign of $OV = OP - (r_2 - q_2)p_2 S_D$? I have not been able to deduce any specific results from this general formulation of the problem. But it seems likely that the answer will be that it depends on the degree of the individual's risk aversion, the nature and source of demand uncertainty, and the nature of supply uncertainty. I say this on the basis of separate analyses of the uncertain demander facing $q_1 = 1$ and $r_2 = 1$ and the case of a certain demander confronted with various patterns of supply uncertainty.

I will only briefly summarize some results of the analysis of demand uncertainty, since these results are available elsewhere (Hartman and Plummer, unpublished, and Freeman 1984).

As has been known since Schmalensee (1972), option price can be either greater than or less than expected surplus.

The key determinant of the sign of option value is the relationship between the marginal utilities of income in the two states of the world: the good is demanded, and the good is not demanded. If the marginal utility of income is higher in the state of the world in which the resource is not demanded option price will be less than expected surplus and option value will be negative. The economic intuition behind this result is straightforward. If the marginal utility of income is higher in the "no demand state", the option price scheme of payment means that there is a nonzero probability that the individual will have to make the payment of OP using high marginal utility dollars. But if payment is required only in the demand state, the individual is assured of being required to pay only with low marginal utility dollars. The prospect of perhaps having to pay with high marginal utility dollars reduces the size of the sure payment (OP) that the individual is willing to commit himself to make.

If demand uncertainty arises because the individual is uncertain of his income, then option value will be negative for the risk averse and positive for the risk preferring individual. At least if the use of the resource is a normal good, the state of the world with higher income corresponds to demanding the good; and for the risk averse individual, the marginal utility of income is lower in this state. Thus the individual will prefer a scheme requiring payment only in the state of the world in which income is high and the good is demanded.

If demand uncertainty arises because of uncertainty about the price of a complement good (for example, the price of travel to the resource), option value will be positive for the risk neutral and risk preferring individual. In the state of the world where the price of the complement is low, the resource is demanded, and the purchasing power and marginal utility of a dollar of income are higher. Thus the individual would prefer the option price scheme with its chance to make payments with lower marginal utility dollars. But for the risk averse individual, the sign of option value depends on what happens to the marginal utility of income as the price of the complement changes.

Where demand uncertainty arises because of state dependent preferences, one must know something about the shapes of the alternative utility functions. If the marginal utilities are the same, option value is zero. If the individual is risk averse, the sign of option value depends on both how the marginal utility of income schedules differ between the two states and how much the marginal utility of income in the demand state increases because of the payment of S.

In a forthcoming paper I have analyzed the case of supply uncertainty for a certain demander. Again since the results are available elsewhere, I will only state the conclusions here without offering proofs.

Four possible cases can be distinguished on the basis of whether the option is sure ($r_2 = 1$) or unsure ($r_2 < 1$) and whether or not there is a possibility of supply in the absence of the project. These cases can be summarized as follows:

<u>Case A</u>: No project - No supply

With project - Sure supply $q_2 = 0, r_2 = 1$

<u>Case B</u>: No Project - Possible supply

With Project - Sure supply $q_2 > 0, r_2 = 1$

<u>Case C</u>: No Project - No supply

With Project - Possible supply $q_2 = 0, r_2 < 1$

<u>Case D</u>: No Project - Possible supply

With Project - Possible supply $0 < q_2 < r_2 < 1$

In case A option price equals the increase in expected surplus and option value is zero. But this should be no surprise. There is no uncertainty either with or without the program. Case B has been analyzed by Bishop (1982) and Brookshire, Eubanks, and Randall (1983). They show that option value is positive for risk averse individuals. The intuition is straightforward. In the absence of the program, the individual in effect holds a lottery on Q. The risk averse individual would pay more than the expected monetary equivalent of the lottery (expected S) in order to eliminate the uncertainty associated with the lottery. This supply-side option value is a risk aversion premium. Cases C and D are more complicated. But I have shown that option price can be either greater or less than expected surplus depending on the nature of the individual's preferences and the magnitude of the change in the probability of supply with the project.

The question of the relationship between option price and expected surplus when both demand and supply uncertainty are present is difficult. It clearly depends on the pattern of supply uncertainty as reflected in q_2 and r_2, the degree of demand uncertainty as measured by p_2 and the determinants of demand uncertainty as well as the properties of the indirect utility function. It appears that in the general case the relationship between option price and the increase in expected surplus can only be determined through a quantative analysis based on knowledge of the relevant probabilities and the specific properties of the utility function.

Conclusions

As the preceding analysis has shown, it is at best misleading to speak of option value as a separate category of benefits. Option value is defined as the algebraic difference between two different concepts of welfare change, the ex ante concept (the money equivalent of the change in expected utility) and the ex post concept (the change in expected consumer surplus). As such, option value can be either greater than zero or less than zero depending upon the structure of preferences and the nature of the uncertainties involved.

The theoretical analysis of option value may prove to be most useful through providing a bridge between the two different concepts of welfare change. For example in the case of demand uncertainty it may be possible to use indirect techniques such as the travel cost method to estimate the consumer surpluses of users of the resource. If observed users can be assumed to represent a random sample of all potential users, then the observed consumer surplus is an estimate of the expected consumer surplus of all uncertain demanders. Then, if the causes of demand uncertainty can be adequately characterized, it may be possible to compute option prices by making some assumption about the functional form and parameters of the von Neumann-Morgenstern indirect utility function.[7] Similarly for the case of supply uncertainty, estimates of of consumer surpluses realized when the good is supplied may provide the basis for calculating option price, if the latter is the desired welfare measure. But option value is simply a byproduct of such calcuations. It cannot be computed independently. And it is not a separate component of the total benefits of providing the environmental resource.

III. POLICY UNCERTAINTY AND QUASI-OPTION VALUE

When decisonmakers are uncertain about the magnitude of the benefits and/or the costs of alternative courses of action, decision rules and procedures must be modified to reflect this uncertainty. One possible modification entails altering the time sequence of choices so as to take advantage of information that might become available in the future. The term "quasi-option value" was coined by Arrow and Fisher (1974) to describe the welfare gain or benefit associated with delaying a decision when there is uncertainty about the payoffs of alternative choices and when at least one of the choices involves the irreversible commitment of resources. They showed that quasi-option value is not dependent on risk aversion. It can be present even when decisionmakers make choices on the basis of basis of expected values of uncertain variables.

Most of the literature on the role of this concept in environmental decisionmaking has concluded that consideration of quasi-option would lead to relatively less irreversible development and relatively more preservation of natural environments. However the conclusion that there is a quasi-option value benefit to preserving a natural area or to delaying its development springs from a specific feature of the models used by Arrow and Fisher (1974), Krutilla and Fisher (1975), Conrad (1980), and others. As Conrad has shown, quasi-option value is essentially the expected value of the information gained by delaying an irreversible decision to develop a natural area. But it is not difficult to imagine situations where the relevant information to guide future decisions can be gained only by undertaking now at least a little development. In such cases there can be positive quasi-option value to development, or, what is the same thing, a negative quasi-option to preservation. Whether quasi-option value exists or whether it is positive or negative for preservation depends on the nature of the uncertainty, the opportunities for gaining information, and the structure of the decision problem. Since this point has been established in recent papers by Lad and Miller (1984) and myself (1984b), it should not be necessary to go through the demonstration here.[8]

What is shown in these papers is that quasi-option value is not a one-sided argument in favor of slower development and greater preservation. Rather it is an argument for seeking out and evaluating all of the possible strategies that will yield information about uncertain magnitudes. In many cases valuable information can be gained by waiting. If the uncertainty is due to lack of information about preservation benefits, then waiting and carrying out the appropriate research can be sufficient to resolve the uncertainty. In this case it is the waiting and research strategy that creates option value. But if the uncertainty arises from lack of information about the gross returns or investment costs of development, then this uncertainty might be reduced by undertaking a little development while preserving the option of not undertaking full development if the experiment turns out badly. If this is the case, then it is the act of development which generates quasi-option value. Thus consideration of quasi-option value is likely to favor relatively less development only when the uncertainty concerns the magnitude of preservation benefits and when postponing the development decision and carrying out the appropriate research are likely to resolve this uncertainty. These papers also show that quasi-option value is not a magnitude which can be estimated separately and added into a benefit cost calculation. Rather it is a value whose magnitude is revealed by the comparison of two strategies where one of the strategies involves sequential decision making to take advantage of information obtained as part of the optimal strategy.

IV. CONCLUSIONS

The title of this sessions poses the question: Is option value a central concept for environmental policy making? Or is it merely a theoretical anachronism? A similar question can be asked about quasi-option value. I find it interesting that the answers to these questions are essentially the same. They are both valid theoretical constructs, that is, they can be defined in terms of logical, internally consistent models based on accepted economic concepts and assumptions. But in both cases the early models turned out to be special cases. The quasi-option value model made special assumption concerning how uncertainty was resolved. The demand uncertainty option value model abstracted from uncertainty in supply. Furthermore, it was eventually shown in both cases that option value and quasi-option value could be either greater or less than zero and could be better understood as the algebraic difference between two other measures.

The early literature implied that these concepts could be measured separately and then added to other components of benefits when conducting a benefit-cost analysis. But this is turned out not to be the case. It turns out that if we have sufficient information to compute option value or quasi-option value, the computation is essentially superfluous. Thus these two concepts do not appear to be "central concepts" for environmental policy making. However, the theoretical analyses of option value and quasi-option value have been very important in gaining a better understanding of the problems of measuring welfare change and policy decisionmaking under uncertainty.

In closing, I would like to call attention to another similarity in the evolution of the concepts of option value and quasi-option value. In rereading the early literature on these two topics, it is easy to develop the suspicion that these concepts were "discovered" in the process of searches to find additional types of benefits to include in the benefit-cost analyses of environmental preservation versus development issues.[9] I realize that in saying this I may be appear to be casting stones at some well known and respected names in our profession. But I excuse myself by pointing out that one of those stones is aimed directly at my own glass house. I think that this notion of wishful thinking about option value and quasi-option value would be an interesting idea to pursue when the history of these particular areas of economic thought are written.

FOOTNOTES

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[1]It is important to note that the presence of one form of uncertainty does not necessarily imply the other. In principle, the policy maker could have perfect information on the economic value of the reduction of environmental uncertainty to individual users of the environment. And policy makers could be uncertain as to the magnitudes of the benefits and costs even when the uncertainties faced by individuals are insignificant.

[2]Ulph (1982) discusses some of these questions in the context of the social value of lifesaving.

[3]Since prices are assumed constant, I omit the price term for notational simplicity.

[4]See Cook and Graham (1977) for further discussion.

[5]Such payments might be particularly difficult to administer if the source of uncertainty were on the demand side rather than the supply side. See Graham (1981).

[6]On these points see also Graham (1981) and Mendelsohn and Strang (forthcoming).

[7]See Freeman (1984) for examples of such calculations.

[8]Also see Hanemann (1983) for a careful and illuminating analysis of uncertainty, information, and quasi-option value.

[9]For example, Milton Friedman's (1962) argument for subjecting the preservation of wild lands and national parks to a market test was the first work cited by Weisbrod (1964).

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Supply Uncertainty, Option Price, and Option Value: A Note

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I.

The term "option value" has been applied to the case where an individual who is uncertain as to whether he will demand a good in some future period is faced with uncertainty in the supply or availability of that good. The term option price refers to the maximum willingness to pay for a project which preserves the option to consume the good in the future. Option value is the excess of option price over the expected consumer surplus given that the good is supplied. It has been established that option value, defined in this manner, can be either positive or negative. The sign and magnitude of option value depend upon the source and nature of demand uncertainty and the individual's attitude toward risk.[1]

As Bishop has pointed out (1982, p. 2), the work to date has focused on the role of demand uncertainty with no explicit analysis of uncertainty on the supply side. In fact, in the models reviewed in Bishop, the good in question is either supplied with certainty if the option price is paid or is not supplied at all if the option price is not paid, in other words, uncertainty in supply is assumed away. Two recent papers have begun the analysis of supply uncertainty by considering the simple case where the individual is certain of his demand for the good (Bishop, 1982; Brookshire, Eubanks, and Randall, 1983).[2] These authors have offered proofs that where only supply side uncertainty is involved, what might be called "supply-side option value" is greater than zero for the risk averse individual.[3] In this paper I will show that the previous authors' analysis of supply-side uncertainty is incomplete. They have considered only one of four possible patterns of supply uncertainty. I will show that although the finding about positive supply-side option value is correct in the special case considered by Bishop and Brookshire, Eubanks, and Randall, in other more general cases, the sign of supply-side option value is indeterminate.

This paper has two objectives. The first is to provide a complete characterization of supply-side uncertainty both with and without the project supplying the good. In the absence of the project, the probability of supply of the good could be either zero or positive; and the project could either increase the probability of supply while leaving some uncertainty, or it could eliminate the uncertainty in supply by increasing the supply probability to one. I will examine the relationship between option price and expected consumer surplus in each of the four possible combinations of probabilities of supply without and with the project.

The second objective of the paper is to examine some of the implications of introducing demand uncertainty into a model which allows for all of the possible cases of supply side uncertainty. When the sign of option value depends on the nature and the source of both supply and demand uncertainty, no simple generalizations appear to be possible. But the model provides a framework for considering specific cases that might arise in practice.

II.

Let us assume that an individual's utility depends upon the level of income, Y, and the level of provision of a public good, G. Assume that income and all prices are known with certainty and that preferences are independent of the state of the world. These assumptions eliminate uncertainty concerning demand for the public good. Also assume that there are no contingent claims markets.[4] Finally assume that there are two possible levels of supply of the public good, $\bar{G} > 0$ and 0. The compensating surplus measure of consumer surplus for the public good is defined by:

$$U(Y, 0) = U(Y - CS, \bar{G}) = \bar{U} \tag{1}$$

Assume that $U(\cdot)$ is characterized by diminishing marginal utility of income, or equivalently, that the individual is risk averse.

In the absence of a project that serves to reduce the uncertainty of supply, the probability that the good will be supplied is $0 \leq q_2 < 1$;[5] and expected utility is:

$$E_N = q_1 U(Y, 0) + q_2 U(Y, \bar{G}) \tag{2}$$

where $q_1 = 1 - q_2$. Now assume that with the project the probability of supply is $r_2 > q_2$. Option price, OP, is that sure payment for the project that equates the expected utilities with and without the project. OP is defined by:

$$E_N = E_O \tag{3}$$

where:

$$E_O = r_1 U(Y - OP, 0) + r_2 U(Y - OP, \bar{G})$$

Thus the general expression relating option price and CV is:

$$q_1U(Y, 0) + q_2U(Y, \bar{G}) \tag{4a}$$

$$= r_1U(Y - OP, 0) + r_2U(Y - OP, \bar{G})$$

or by substitution of (1):

$$q_1U(Y - CS, \bar{G}) + q_2U(Y, \bar{G})$$

$$= r_1U(Y - OP, 0) + r_2U(Y - OP, \bar{G}) \tag{4b}$$

In the most general analysis, four possible cases can be distinguished on the basis of whether the option is sure ($r_2 = 1$) or unsure ($r_2 < 1$) and whether or not there is a possibility of supply in the absence of the project. These cases can be summarized as follows:

Case A:	No Project - No supply With Project - Sure supply	$q_2 = 0,\ r_2 = 1$
Case B:	No Project - Possible supply With Project - Sure supply	$q_2 > 0,\ r_2 = 1$
Case C:	No Project - No supply With Project - Possible supply	$q_2 = 0,\ r_2 < 1$
Case D:	No Project - Possible supply With Project - Possible supply	$0 < q_2 < r_2 < 1$

Each of these cases can be analyzed by imposing the appropriate probability conditions on equation (4) and solving for OP.

In order to examine the relationship between OP and expected compensating surplus, we must be explicit about which probabilities to use in calculating the latter term. The relevant comparison is between the option price that is paid for the project and the increase in expected surplus with the project, $(r_2 - q_2)$ CS.

For Case A ($q_2 = 0$, $r_2 = 1$), equation (4) reduces to $U(Y - CS, \overline{G}) = U(Y - OP, \overline{G})$. Therefore:

$$OP = CS = (r_2 - q_2)CS$$

Option price equals the increase in expected surplus and SSOV is zero. But this should be no surprise. There is no uncertainty either with or without the project.

For Case B ($q_2 > 0$, $r_2 = 1$), equation (4) becomes:

$$q_1U(Y - CS, \overline{G}) + q_2U(Y, \overline{G}) = U(Y - OP, \overline{G})$$

Bishop, and Brookshire, Eubanks, and Randall present (respectively) mathematical and graphical proofs that SSOV is positive for risk averse individuals. The proofs need not be repeated here.[6] The intuition is straightforward. In the absence of the project, the individual in effect holds a lottery on G. The risk averse individual would pay more than the expected monetary equivalent of the lottery (expected CS) in order to eliminate the uncertainty associated with the lottery. This supply-side option value is a risk aversion premium.

For Case C ($q_2 = 0$, $r_2 < 1$), equation (4) becomes:

$$U(Y - CS, \overline{G}) = r_1U(Y - OP, 0) + r_2U(Y - OP, \overline{G}) \quad (5)$$

In this case, the sign of SSOV is indeterminate. A mathematical proof requires the introduction of two new terms.[7] Let $Y^* \equiv Y - OP$; and define CS^* such that

$$U(Y^* - CS^*, \overline{G}) = U(Y, 0) = U(Y - OP, 0) \qquad (6)$$

Strict concavity of U in income implies:

$$U\left[r_1(Y^* - CS^*) + r_2Y^*, \overline{G}\right] > r_1U(Y^* - CS^*, \overline{G}) + r_2U(Y^*, \overline{G}) \qquad (7)$$

Rearranging the left-hand side of (7) and using (6) and the definitions for substitutions on the right-hand side yield:

$$U(Y^* - r_1CS^*, \overline{G}) > r_1U(Y - OP, 0) + r_2U(Y - OP, \overline{G})$$

or from (5):

$$U(Y - OP - CS^* + r_2CS^*, \overline{G}) > U(Y - CS, \overline{G})$$

Thus

$$- OP - CS^* + r_2CS^* > - CS$$

or after some rearranging

$$OP - r_2CS < (1 - r_2)(CS - CS^*) \qquad (8)$$

If the individual's total willingness to pay for G is independent of income (that is, if $CS = CS^*$), then option price is less than the increase in expected surplus and SSOV in negative. But in the usual case that G has a positive price flexibility of income, then $CS > CS^*$.[8] Although (8) must hold, OP could exceed r_2CS resulting in positive SSOV. Thus the sign of SSOV in this case is indeterminate.

Case D is described by equation (4) with $0 < q_2 < r_2 < 1$.

The fact that the individual has some prospect of experiencing $\overline{G}$ even in the absence of the project does not alter the basic structure of the problem. The maximum state independent payment for the project is less than the increase in expected surplus when the price flexibility of income for G is zero. But OP can exceed $(r_2 - q_2)$CS when the price flexibility of income is positive.[9]

III.

In this section, I consider some of the implications of adding supply-side uncertainty to the standard option value model based on uncertainty of demand. I show that the standard formulation of the demand-side option value model (e.g., Schmalensee; Bishop) may not be the correct one for determining the option price of a project which reduces or eliminates supply uncertainty for uncertain demanders. The problem is that the demand-side option value models have been formulated so as to determine the maximum willingness to pay for a sure option on the assumption that the individual will be excluded from consuming the good if the option price is not paid. In other words, they assume only one of the four possible cases of supply-side uncertainty, specifically Case A. The estimates of demand-side option value that emerge from such analyses are estimates of the value of hedging against demand-side uncertainty in a situation in which supply-side uncertainty has been eliminated. This may be the relevant model for many kinds of policy questions, for example, whether to destroy the park now or preserve it for future uncertain demanders. But there may be many cases in which either the project can only reduce but not eliminate supply uncertainty or where there is a positive probability of continued supply even without the project.[10]

There are two questions to be addressed concerning the integration of demand- and supply-side uncertainty. The first is the effect of inappropriate assumptions about supply-side uncertainty on measures of option price when demand uncertainty is present. The second is the sign of option value when supply-side and demand-side uncertainty are integrated. Demand uncertainty can arise from uncertainty about income, uncertainty about the prices of other goods, or state dependent preferences. For purposes of this analysis, it is not necessary to specify the sources of demand uncertainty. Let p_2 be the probability of demanding the good. The indirect utility function when the good is demanded can be represented by

$$U_D(Y_D, P_D, G)$$

while with no demand it is:

$$U_{ND}(Y_{ND}, P_{ND})$$

where P_{ND} and P_D represent price vectors. If the good is demanded and supplied, realized utility is higher than if the good is not supplied:

$$U_D(Y_D, P_D, \overline{G}) > U_D(Y_D, P_D, 0) = U_D(Y_D - S, P_D, \overline{G}) \qquad (9)$$

If the good is not demanded, the individual is indifferent as to supply.

Before the project which would reduce supply uncertainty, the individual's expected utility, E_N, is

$$E_N = p_1 U_{ND}(Y_{ND}, P_{ND}) + p_2 \left[q_1 U_D(Y_D, P_D, 0) + q_2 U_D(Y_D, P_D, \bar{G})\right] \quad (10)$$

Consider now a project which would reduce supply uncertainty. As before, option price is that state independent payment which makes expected utility with the project (E_O) equal to E_N, or

$$E_N = E_O = p_1 U_{ND}(Y_{ND} - OP, P_{ND}) \quad (11)$$

$$+ p_2 \left[r_1 U_D(Y_D - OP, P_D, 0) + r_2 U_D(Y_D - OP, P_D, \bar{G})\right]$$

In the standard model, it is assumed that $q_2 = 0$ and $r_2 = 1$, that is that supply uncertainty is of the Case A variety. Option price is defined by:

$$p_1 U_{ND}(Y_{ND}, P_{ND}) + p_2 U_D(Y_D, P_D, 0) = \quad (12)$$

$$p_1 U_{ND}(Y_{ND} - OP, P_{ND}) + p_2 U_D(Y_D - OP, P_D, \bar{G})$$

But neither assumption about probabilities must necessarily hold in practice. In Case B ($q_2 > 0$, $r_2 = 1$) the left-hand side of (12) becomes:

$$p_1 U_{ND}(Y_{ND}, P_{ND}) + p_2 q_1 U_D(Y_D, P_D, 0) + p_2 q_2 U_D(Y_D, P_D, \bar{G}) \quad (13)$$

As can be seen by comparing (13) with the left hand side of (12) and recalling the inequality of (9), the expected utility without the project is increased by the presence of case B supply uncertainty. Thus OP must be lower than in case A. In case C ($q_2 = 0$, $r_2 < 1$), the right-hand side of (12) becomes:

$$p_1 U_{ND}(Y_{ND} - OP, P_{ND}) + p_2 r_1 U_D(Y - OP, P_D, 0) + \quad (14)$$

$$p_2 r_2 U_D(Y - OP, P_D, \bar{G})$$

surplus. And second when full account is taken of supply-side uncertainty, the relationship between option price and the increase in expected surplus for uncertain demanders becomes more complicated and no simple generalizations appear to be possible.

Footnotes

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[1]See Schmalensee (1972). For recent surveys and reviews of the theoretical issues, see Bishop (1982) and Smith (1983). See Freeman (1984) for an analysis of the determinants of the sign and size of option value. In this paper, I do not deal with the question of whether option price or expected consumer surplus (if either) is the correct measure of welfare change. See Graham (1981) and Smith (1983) for discussions of some aspects of this question. The question also involves deeper issues of ex ante vs. ex post welfare criteria. See for example Hammond (1981).

[2]See also Smith (1983, 664-666) for a somewhat different treatment of supply uncertainty.

[3]I think that it is useful to adopt a terminology which distinguishes between the two different sources of possible divergence between willingness to pay and expected surplus. I will

use the term "demand side option value" to refer to the more traditional concept that has been the subject of analysis for authors going back to Weisbrod (1964).

[4]For a discussion of the role of contingent claims markets in determining the willingness to pay to reduce the probability of an adverse outcome, see Cook and Graham (1977), pp. 151-154.

[5]One might take exception to allowing $q_2 = 0$, that is, certainty of no supply. But this polar case is included because of its role in the literature, as will become clear below.

[6]Bishop and Brookshire, Eubanks, and Randall both made explicit comparisons between OP and expected surplus without the project, i.e. q_1CS. Thus at first glance it appears that they were comparing the wrong magnitudes. However given the assumptions about probabilities, their comparisons are algebraically equivalent to the correct one, i.e., $(r_2 - q_2)$CS given $r_2 = 1$ and $(1 - q_2) = q_1$.

[7]I am indebted to John Fitzgerald for suggesting this proof to me.

[8]The behavior of CS as a function of income is the basis of the Cook and Graham's measure of the irreplaceability of a good (1977),

$$\frac{dCS}{dY} = 1 - \frac{\partial U(Y,0)/\partial Y}{\partial U(y-CS,\bar{G})\,\partial Y}$$

According to (8) if G is replaceable in this since (dcs/dY = 0), then SSOV must be negative. Smith (1984) also uses the index of irreplaceability or uniqueness in establishing bounds on demand side option value.

[9] I have not been able to find a straightforward mathematical proof for Case D. But numerical calculations with various assumed parameters and utility functions confirm the indeterminancy of the sign of OP - $(r_2 - q_2)$CS. Examples of these calculations are available from the author.

[10] For example bighorn sheep hunters in the Brookshire, Eubanks, and Randall study faced a non-zero probability of being able to hunt in the absence of the project. The project was assumed to increase the probability that hunters would obtain licenses.

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NUMERICAL CALCULATIONS
OF SUPPLY-SIDE OPTION VALUE

by

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This note is a supplement to my "Supply Uncertainty, Option Price, and Option Value: A Note." All concepts, definitions and notations are explained there. The purpose is to show that supply-side option value $[OP - (r_2 - q_2)CS]$ can be either positive or negative in the most general case.

I. CS IS INDEPENDENT OF INCOME

The general form of the utility function is $U = U(Y, G)$ for $G = 0, \bar{G}$. The condition that CS is independent of income is embodied in $U = U(Y + G)$ so that $CS = \bar{G}$; that is:

$$U(Y + S + \bar{G}) = U(Y + 0)$$

A. Let $U(Y, G) = (Y + G)^b$ for $0 < b < 1$

Assume the following values:

$$Y = 20{,}000 \quad CS = \bar{G} = 2000$$

$$b = .5$$

$$q_1 = .75,\ q_2 = .25,\ r_1 = .25,\ r_2 = .75$$

Thus $(r_2 - q_2)CS = 1000$.

From Equation (4), OP is the solution to

$$q_1U(Y, O) + q_2U(Y, \bar{G}) = r_1U(Y - OP, O) + r_2U(Y - OP, \bar{G})$$

$$.75(20{,}000)^{.5} + .25(22{,}000)^{.5} = .25(20{,}000 - OP)^{.5} + .75(22{,}000 - OP)^{.5}$$

or $143.14701 = .25(20{,}000 - OP)^{.5} + .75(22{,}000 - OP)^{.5}$

Solving for OP is cumbersome, but the RHS is E_0. Calculate E_0 for various values of OP*. If $E_0 > 143.14701$, then $OP^* < OP$.

Try $OP^* = (r_2 - q_2)CS = \$1000$.

$$E_0 = .75(19{,}000)^{.5} + .75(21{,}000)^{.5}$$

$$= 143.14545 < 143.14701$$

Thus $OP^* = (r_2 - q_2)CS > OP$

and SSOV < 0.

Similar calculations for $r_1 = .7$, $r_2 = .3$

and $(r_2 - q_2)CS = 100$ show

$$143.14701 > .7(20{,}000 - 100)^{.5} + .3(22{,}000 - 100)^{.5} = 143.14310$$

So $OP < (r_2 - q_2)CS$.

B. Let $U(Y, G) = \frac{1}{1 - b}(Y + G)^{1-b}$

Assume $Y = 20{,}000$ $CS = \overline{G} = 2000$

$b = 10$

$q_1 = .75$, $q_2 = .25$; $r_1 = .25$, $r_2 = .75$

From (4), solve

$$\frac{1}{-9}\left[.75(20{,}000)^{-9} + .25(22{,}000)^{-9}\right] = \frac{1}{-9}\left[.25(20{,}000 - OP)^{-9} + .75(22{,}000 - OP)^{-9}\right]$$

for OP. Trying $OP^* = (r_2 - q_2)CS = 1000$

yields

$$1.679 \times 10^{-39} > 1.719 \times 10^{-39}$$

so $\quad OP^* < OP \quad$ and $\quad OP < (r_2 - q_2)CS.$

II. CS IS AN INCREASING FUNCTION OF INCOME

Let $\quad U = (a + G)^c \, Y^b \qquad 0 < b, c, < 1$

For any a, b, c, Y, and $\overline{G}$, the following can be solved for S:

$$(a)^c \, Y^b = (a + \overline{G})^c (Y - S)^b$$

Alternatively, if S is specified, this can be solved for $\overline{G}$, thereby scaling G. Then (4) can be solved for OP:

$$OP = Y - \left[\frac{q_1 (a + \overline{G})^c (Y - S)^b + q_2 (a + \overline{G})^c (Y)^b}{r_1 (a)^c + r_2 (a + \overline{G})^c} \right]^{\frac{1}{b}}$$

Assume $\quad Y = 20{,}000 \qquad CS = 2000$

$b = .1 \quad , \quad c = .1 \quad , \quad a = 1$

$q_1 = .75, \; q_2 = .25; \; r_1 = .25, \; r_2 = .75$

$(r_2 - q_2)CS = 1000$

Thus $\overline{G} = .111$

$$OP = 20{,}000 - \left[\frac{.75(1.111)^{.1}(18{,}000)^{.1} + .25(1.111)^{.1}(20{,}000)^{.1}}{.25(1)^{.1} + .75(1.111)^{.1}} \right]^{10}$$

$= 1026.33 > (r_2 - q_2)CS.$

Alternatively, if $b = .9$, $\overline{G} = 1.5811748$

and $\quad OP = 1025.77 > (r_2 - q_2)CS$

THE VALUATION OF RISK REDUCTIONS ASSOCIATED WITH REGULATORY POLICIES

V. Kerry Smith and William H. Desvousges*

I. INTRODUCTION

This paper describes a conceptual framework for valuing regulations designed to reduce the risks experienced by individuals. While the motivation for our research arises from concern over the valuation of regulations governing the disposal of hazardous wastes, the analysis is general and could be applied to any risk reducing regulation. Nonetheless, in an effort to provide some specificity to the analytical concepts, we will use hazardous waste regulations for our examples. In contrast to the approach conventionally used to value regulations designed to improve other aspects of environmental quality, such as air or water quality, we have assumed these regulations affect the risk experienced by an individual. That is, we do not attempt to isolate a specific dimension of environmental quality that is uniquely associated with the disposal of hazardous wastes. While hazardous wastes are most often associated with contamination of water supplies, especially groundwater, exposure to airborne hazardous pollutants is also possible.

For our purposes, one of the most important aspects of the problem arises from what the regulations can be expected to provide. They do not guarantee a level of environmental quality.

It must be recognized that, given our knowledge of the generation and transportation, as well as the current and proposed disposal practices, there is some risk that individuals will be exposed to hazardous substances at all plausible levels of regulation.[1] Consequently, increased stringency of disposal regulations in our framework serves to reduce the risk of exposure. An economic evaluation of the policy associated with these regulations requires estimating the risk changes attributable to this increased stringency and valuing them. That is, we must model and measure households' valuations of these risk reductions. This paper is concerned with the first of these tasks. In subsequent research we will report the results of a survey of over 600 households in suburban Boston that utilizes contingent valuation techniques to elicit households' willingness to pay for risk reductions.

It is possible to provide a more tangible basis for our analysis by considering two scenarios outlined by Freeman [1984a] that represent the types of cases that involve hazardous wastes in actual policy decisions. Each describes a sequence of events that might lead to exposures to hazardous wastes. The first involves a short-term contamination incident that could result from an accidental spill of these wastes. For example, we might assume that the substances involved were organic solvents, acids, or inorganic toxics which can be acutely toxic but have relatively short environmental half lives. An equivalent scenario, in terms of the time period for the risk of exposure, could be defined by assuming there was early detection of hazardous substances with longer resonance times but there was a technology capable of completely effective cleanup and with that cleanup the elimination of the risk of exposure. We will distinguish the evaluation of policies associated with these short-term risks from the second category described by Freeman. In this second scenario, Freeman used a scenario involving the long-term seepage of a hazardous substance with characteristics of persistence, bioconcentration, and chronic toxicity into environmental media. Detection of such substances is difficult. Therefore individuals must be assumed to face a long-term, but low risk of exposure to these substances. Our analytical model and associated valuation concepts are more relevant to changes in a long term risk. Consequently, this second scenario is probably the most plausible source of the risk described in our model.

The risk reductions we wish to value arise because more stringent disposal regulations require alterations in disposal practices. We can conceive of these as analogous to the safety concepts used in discussions of the risks associated with nuclear power plants -- the so called "defense in depth" concepts of the effects of safety related technologies. Under this view of the effects of regulations, landfills would be required to adopt containment technologies that have multiple liners and/or detection systems for leaks. Increased safety requires systemst that duplicate one another or, equivalently, that attempt to respond to component failures. For example, we might assume that as a result of the regulations disposal sites would be required to introduce, parallel defense systems would permit each level to mitigate failures experienced with lower level systems. In such hazardous substances with longer resonance times but there was a technology capable of completely effective cleanup and with that cleanup the elimination of the risk of exposure. We will distinguish the evaluation of policies associated with these short-term risks from the second category described by Freeman. In this second scenario, Freeman used a scenario involving the long-term seepage of a hazardous substance with characteristics of persistence, bioconcentration, and chronic toxicity into environmental media. Detection of such substances is difficult. Therefore individuals must be assumed to face a long-term, but low risk of exposure to these substances. Our analytical model and associated valuation concepts are more relevant to changes in a long term risk. Consequently, this second scenario is probably the most plausible source of the risk described in our model.

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There has been surprisingly little research on the evaluation of policies designed to change the risks experienced by households. One notable exception arises with the literature associated with option values for unique environmental resources. In this case, an individual is viewed as making an <u>ex ante</u> payment in order to resolve some of the uncertainty that he (or she) faces. In the earliest discussions of option value (see Bishop [1982] and Smith [1983] for reviews) these payments resolved uncertainty as to whether some resource would be supplied. They did not, however, eliminate a second uncertainty the individual was assumed to face. The individual was assumed to be uncertain as to whether the good or service involved actually would be desired.

More recent research (Brookshire, Eubanks and Randall [1983] and Freeman [1984b]) has considered cases in which the payment of an option price changed, but did not resolve the uncertainty. That is, these models assumed the option price would increase the likelihood of some desirable state. These analyses are closely related to the valuation problem to be addressed here. However, they have failed to recognize that an individual's valuation of some increase in the probability of a desirable state (or equivalently reduction in the probability of an undesirable one) depends upon the opportunities available for adjustment to that risk. The specification of the framework associated with the payment of an option price maintains one assumption for these opportunities. There are others and an individual's marginal valuation of the effects associated with a policy will depend on what is assumed.

Equally important, the focus of past theoretical analyses of option price has largely been directed to comparisons of option price and expected consumer surplus (i.e., to the sign and magnitude of option value). We will argue that this is misleading, because it requires a comparison of two distinct perspectives for applied welfare analysis -- an ex ante versus an ex post criterion. Thus, while this literature provides important insights to the valuation problem, it does not provide a basis for dealing with the problem of valuing the risk reductions associated with regulations on the disposal of hazardous wastes.

Section II begins our analysis with a general overview of the expected utility framework as a basis for valuing risk changes. Graham's [1981] framework for analyzing option price is used to describe how institutions can affect the valuation of risk reductions through their implications for the prospects for the diversification of risks. Section III develops our basic model, and considers the implications of state-dependent utility functions for the valuation of risk changes. We also consider the relationship between these valuation concepts and the option price. The last summarizes the paper and discusses its implications for the estimation of the value of risk reductions.

II. UNCERTAINTY AND THE CHOICE OF A PERSPECTIVE FOR BENEFIT ANALYSIS

There has been increasing acceptance of a taxonomy for describing the components of the benefits associated with a change in the quantity or the quality of an environmental resource. This framework distinguishes user and nonuser (or intrinsic) benefits. Within the latter category option, existence, and bequest values are often identified as constituents.[2] Unfortunately, this scheme can be confusing, because the conventional definitions of user and option values have implicitly adopted <u>different</u> perspectives for the valuation of environmental resources. This difference has not been completely appreciated until recently. To the extent there is uncertainty in an individual's consumption, the perspective - *ex ante* versus *ex post* -- must be recognized in the definition of valuation concepts. Moreover, when the policy to be evaluated involves a change in the uncertainty itself, the selection of a perspective for analysis can be important.

The perspective relates to the view of the decision process.

In effect, are we attempting to value a change in a resource (or its conditions of availability) based on how the change affects an individual's planned consumption? Or, alternatively, is the value derived as the expected value of the modification in actual consumption that would arise from the resource change. These two values need not be the same (see Smith [1984b]).

The first corresponds to an ex ante view of the valuation problem, while the second involves an ex post perspective. In what follows, we will utilize an ex ante framework, but will note the ways in which the selection of a perspective can affect benefits analysis.

A. The Expected Utility (EU) Framework

Our analysis will accept the contingent commodity (or contingent claims) approach to describing the effects of uncertainty on individual decision making. This means that our model will relate to planned consumption patterns, for any state of nature that is realized. Utility will be described with a Von Neumann-Morgenstern utility function with the conventional assumptions of nonsatiation and risk aversion (i.e., concavity).

The central assumptions for the behavioral properties of expected utility maximization are generally recognized as some variation on three axioms: transitivity of preferences over lotteries, continuity of preferences over lotteries, and the independence axiom.[3] The assumptions of transitivity and continuity imply an individual's preference ranking over lotteries can be described using a preference functional described over the distributions for these lotteries. Independence gives the theory its empirical specificity by restricting the form of this preference functional.

A complete description of the experimental record on the performance of the model is not warranted here since a number of summaries are available in the literature (see for example Schoemaker [1980], [1982], and Machina [1983]). However, it is important to recognize that judgements as to its applicability to real-world decisionmaking under uncertainty need not be as[4] pessimistic as Schoemaker's [1982] summary. As Machina acknowledges, there remain several potential explanations for the violations that are, at least, locally consistent with the expected utility framework. Equally important, there has not been a complete and empirically viable alternative framework for describing behavior. Consequently, our analysis accepts the expected utility framework as a basis for defining valuation concepts.

Without loss of generality, we can assume that an individual is allocating income among contingent claims. Whatever state is realized, he (or she) will seek to allocate this income to maximize utility subject to the constraints of budget exhaustion and fixed prices. This implies that an indirect utility function can be used to describe an individual's preferences in the ith state as in equation (1):

$$(1) \quad U_i = V_i(Y_i, P_i, Q_i)$$

where Y_i = income

P_i = price vector

Q_i = level of an environmental amenity (or disamenity) given exogenously

Holding P and Q constant, assuming there are two states of nature and that total income, Y, can be allocated to different contingent income claims W_1 and W_2 associated with each of the two possible states of nature, the individual's objective function can be written as:

$$(2) \quad EU = p\, V_1(W_1) + (1-p)\, V_2(W_2)$$

with p = the probability of state one

EU = expected utility

We have suppressed P and Q in (2) since they are assumed to be constant in the initial analysis with this model. If these claims for income are available at prices r_1 and r_2, then the budget constraint relevant to the allocation problem defined by (2) is given as equation (3).

$$(3) \quad Y = r_1 W_1 + r_2 W_2$$

The solution to this maximization problem is well know. The ratio of expected marginal utilities will be equalized to the relative prices of claims. If we can assume that the prices of claims correspond to a "fair bet", then marginal utilities will be equal for the two states. Of course, for the case of state independent preferences with equal P_i's and Q_i's, this implies incomes are equalized between the two states. Thus, the income assigned to the claims associated with each state will be equal; the marginal utilities will be equal; and the total utilities will be equal.[5]

By re-introducing one of the arguments of V(.) suppressed earlier, this model can be used to define conventional measures of the benefits associated with increases in environmental amenities and relate them to the measures defined for changes in the uncertainty facing the individual. To relate the expected utility framework to a specific problem, a source for the uncertainty must be identified. Using the two levels of environmental quality, Q, with $Q_2 > Q_1$, we might suppose an individual can be in either of two states - the first offers environmental quality at Q_1, while the second provides the higher level Q_2.[6] The probabilities corresponding to these states are p and (1-p), respectively. This formulation has the effect of converting the model in (2) to one with state-dependent utility functions, where even with actuarially fair prices for the income claims, an individual's allocation of resources will not necessarily equalize incomes among the claims for each state (or total utilities realized in them). If the level of the environmental resources available for consumption affects the marginal utility of income, then we can expect that an individual's insurance purchases at fair odds will <u>understate</u> his marginal valuation of probability changes.

This specification for the source of uncertainty corresponds to what has been described in the literature as supply uncertainty. An alternative formulation could also be derived recognizing that V(.) includes a price vector. If we assume that individual's valuation of Q depended upon his level of consumption of some complementary good, and that there is a price at which none of this good would be demanded, then we have a different source for changes in the indirect utility function. For example, P_a might correspond to a price vector with the price for this complementary good set at a level sufficiently high to preclude consumption, while P would be the base price vector with a positive level of consumption of this commodity. Uncertainty over which of these prices would prevail could be interpreted as "demand" uncertainty, because it does not relate to the availability of good of interest - the environmental resource, Q, - but does affect an individual's valuation of Q. Under the assumption of no supply uncertainty this assumption would also lead to the appearance of a state dependency in the utility function.

B. Institutions and Risk Diversification

For environmental applications, the most familiar institutional arrangement for mitigating risk is that associated the conventional definition of option price. This definition would maintain that both demand (or preference related) and supply uncertainty are present. An individual can choose to pay some fee, the option price, regardless of the state of the world (i.e., with respect to the realization of values for other prices, i.e., price vectors P or P_a) and completely resolve supply uncertainty.

While supply uncertainty plays a role in motivating and describing the choice problem it is omitted from the definition of the option price. Supply uncertainty is, in a genuine sense, resolved in the conventional definition of option price regardless of whether or not the option is purchased. That is, the selection of the benchmark used in defining option price is the lowest availability level for environmental quality. If we let p and (1-p) correspond to the probabilities of P and P_a price vectors respectively, then the option price, OP, is given in (4).

$$(4) \quad p\, V(Y-OP, P, Q_2) + (1-p)\, V(Y-OP, P_a, Q_2) = p\, V(Y, P, Q_1) + (1-p)\, V(Y, P_a, Q_1)$$

An alternative definition of option price considers it a payment for changes in the odds of a desirable state. For example, it might compare the expected utility of paying OP and realizing Q_2 against the expected value of a lottery involving a probability of s of realizing Q_1 and (1-s) of Q_2. These cases have recently been discussed by Freeman.

Before pursuing this definition further, a reformulation of equation (4) can be used to demonstrate the role of institutions for the valuation of risk. This is found in Graham's [1981] willingness to pay locus. It is based on the recognition that with a set of a contingent claims markets, the ex ante payments to assure supply need not be fixed across the states of the world. They can be different.

The selection of a point on the locus therefore corresponds to the acceptance of an assumption concerning the institutions (or adjustment mechanisms) available to the individual for diversifying risk. The fair bet point will always yield the largest expected willingness to pay for resolving supply uncertainty in favor of certain supply of the desired service. However, it implicitly maintains the existence of a specific set of institutions or their equivalent in assuring that the risks faced by the individual are insurable and there are no imperfections in the markets providing that insurance. This generalization was proposed by Graham [1981] to evaluate the appropriate measure of benefits for policies changing the uncertainty facing an individual. It is a constant expected utility locus over all possible pairs (in a two state framework) of payments. Figure 1 illustrates the Graham locus.

More specifically, in Graham's framework, an individual commits to a pair of contingent payments (a_1, a_2). The locus describes the set of such payments that maintain constant expected utility. In Graham's original analysis the level of expected utility corresponded to the initial condition with no access to a resource. The payments assured access. Thus, there was no uncertainty in supply or decision by the individual concerning the level of use of the resource. If

$$\bar{V} = p\ V(Y_1, P, O) + (1-p)\ V(Y_2, P_a, O)$$

then the locus is given as:

$$(5) \quad \bar{V} = p\ V(Y_1 - a_1, P, Q) + (1-p)\ V(Y_2 - a_2, P_a, Q)$$

with Q – designating the level of access to the environmental resource and the slope of the locus given by (6).

$$\text{(6)} \qquad \frac{d\,a_2}{d\,a_1} = -\frac{p\,\frac{\partial V}{\partial Y}\,(Y_1 - a_1,\ P,\ Q)}{(1-p)\,\frac{\partial V}{\partial Y}\,(Y_2 - a_2,\ P_a,\ Q)}$$

This discrete characterization of the problem is not essential. The locus could be defined for differing levels of the resource, the Q_1 and Q_2 distinction in our earlier example, or as Freeman [1984b] proposes for payments to increase the odds of realizing some desirable outcome. What is important for our purpose is the locus' description of the range of opportunities for adjustment that can be assumed to confront an individual. That is, the locus describes how values change with the types of institutions for diversifying risk. For example, consider how an individual arranges to make payments contingent upon the state. Each point on the locus designates a different set of payments yielding the same expected utility level. If the payments are equal regardless of state (the point where the locus crosses the 45^o line) each of the payments corresponds to the option price. If the payments correspond to a point where the slope of the locus equals the ratio of the probabilities, then they correspond to what would arise from complete markets for contingent claims that had fair prices (i.e., the relative prices of claims equaled the relative probabilities). Therefore we can consider each of these points as describing how distinct institutions would lead the individual to make these payments. It is clear that the expected magnitude of the payment will vary with each point on the locus because each point implies a different ability to diversify risk. Thus the Graham framework highlights the implications of specifying the conditions under which payments can be made as an integral part of the definition of valuation concepts.[7] Risk reductions will be less important if it is relatively easy for individuals to diversify the risk they face.

Institutions for diversifying risks are important to an evaluation of policies associated with risk reductions in two ways. First, they affect the appropriate perspective for valuing risk reductions for society as a whole. Second, each person's reported (or measured) valuation of a risk change will depend on his (or her) perceptions of the opportunities for diversification of risk. These opportunities determine, in Graham's terms, the individual's position on the willingness to pay locus.

III. VALUING PROBABILITY CHANGES

In order to demonstrate the effects of institutions on an individual's valuation of risk we must describe how these institutions affect planned consumption. That is, we must specify the prospects and cost of making payments contingent upon the state of nature. The most direct way of incorporating these prospects into a model of consumer behavior is in the specification of markets for contingent claims. Of course, this does not necessarily imply that explicit markets for claims must exist. Rather, the introduction of allocations to contingent commodities with prices is intended to represent the equivalent of opportunities for the individual to make payments contingent on the state of nature. The prices for claims then indicate the terms governing these payments. While these prices can be considered for cases where the opportunities are actuarially fair, this is not required by the introduction of opportunities to allocate. Indeed, in real world applications we would expect that the terms for making state dependent payments would not be actuarially fair.

The analysis to this point has largely been definitional, using the expected values for ex post indirect utility functions with goods assumed to be selected optimally irregardless of the state of nature. The Graham willingness to pay locus implicitly maintains that state dependent payments are adjustments to income. This is a convenient formulation of the problem because it permits one to focus on one argument, income, of state dependent utility functions. The state dependency can then be assumed to arise either as a result of the events at risk or the prices of the goods consumed.[8] It does, however, abstract from a potentially important aspect of using the model in practice -- namely, specifying the commodity or set of commodities that actually provides the basis for state-dependent payments. Indeed, when the adjustment mechanism is not through income, the role of these commodities in the utility function must be considered. In what follows, we will maintain consistency with the past literature by assuming it is possible to adjust the income received in each state. After the analysis has been developed in these terms, we will also sketch how the introduction of specific commodities as the basis for diversification would change the results.

Without loss in generality we can continue to develop the model using two states of the world. In the first of these states an individual will experience a detrimental health effect that is associated with exposure to hazardous wastes. Moreover, for simplicity, we will assume that if the individual was not exposed to the hazardous substances, the likelihood of the health effect would be zero.[9]

The second state is one in which this health effect is not experienced. We will also maintain that these health states do not convert into income equivalents. This assumption is <u>not</u> the same as suggesting a compensating or equivalent surplus could not be defined for the health states (see for examples, Note 6). Rather it is a reflection of the effect of the health state on the individual's marginal utility of income.

To simplify the notation we will specify the state dependent utility functions in terms of the claims to income in each state. Two probabilities will be distinguished -- the likelihood of being exposed to a hazardous waste, R, and the probability of incurring the detrimental effect given an exposure, q. Exposure does not assure that the individual will realize the health effect associated with state one. Thus, if equation (7) specifies the expected utility (EU) realized from allocating claims to income to each state, then by rearranging the terms in (7) we can describe the problem as one involving the two events -- -- exposure and detrimental health effect (caused by that exposure) and its complement, as in equation (8) below. This simplification is possible because we have assumed that the event associated with being exposed to the hazardous substance is only important to the individual because of the likelihood of incurring the health effect. If this assumption were relaxed, then the expected utility function and associated properties of the expenditure function would become more complex. However, the general issues raised by this analysis would be comparable.

$$(7)\quad EU = R\,[q\,V_1(W_1) + (1-q)\,V_2(W_2)] + (1-R)\,V_2(W_2)$$

$$(8)\quad EU = Rq\,V_1(W_1) + (1-Rq)\,V_2(W_2)$$

$$(9)\quad E = r_1 W_1 + r_2 W_2$$

If we also assume that there exist "markets" for contingent claims in both states, then we can define the consumer's choice problem as one of minimizing expenditures on claims that would realize an expected utility level as given in (8). In effect, the constraint governing the purchases of claims in equation (9), together with the definition of the expected utility in (8) provide the basis for deriving a behavioral function describing how an individual's planned consumption choices (in this case allocations to contingent claims) would be affected by parameters to the decision process.

By distinguishing the probability of exposure (R) from the likelihood of the detrimental effect given exposure (q) we have the ability to examine what is implied by alternative types of markets for contingent claims, or equivalently, markets for diversifying risk. For example, it seems reasonable to expect the probability of exposure would be the variable that would change as a result of any regulatory policy designed to control the disposal of hazardous wastes. By contrast, q, the odds of the detrimental effect given exposure, is more likely to be associated with the individual's heredity and health. It is outside the control of regulatory policy as well as largely outside the control of the individual.[10]

Solving the necessary conditions for a minimum of (9) subject to (8) we can derive, for each desired level of expected utility, the expenditure minimizing demands for claims. Substituting these functions in (9) we have the expenditure function in (10).

$$(10) \qquad E = r_1 W_1 (r_1, r_2, Rq, \overline{EU}) + r_2 W_2 (r_1, r_2, Rq, \overline{EU})$$

where $\overline{EU}$ = level of expected utility

Our valuation concept is simply the partial derivative of the expenditure function with respect to the variable assumed to be subject to policy control, namely, the probability an individual faces of being exposed to hazardous wastes.[11] Equation (11) defines this partial derivative. Moreover, it is possible to describe specifically how this derivative is to be interpreted depending on both the specification of individual preferences and the institutions available for risk diversification.

$$\text{(11)} \qquad \frac{\partial E}{\partial R} = r_1 \frac{\partial W_1}{\partial R}^* + r_2 \frac{\partial W_2}{\partial R}^*$$

where an asterisk implies the derivative is for the expenditure minimizing values.

Each assumption that is made with respect to the character of the prices for contingent claims will describe a different institutional setting. More specifically, to define actuarially fair markets we must consider the relationship between the prices of claims and the probabilities of the states of nature associated with these claims. This relationship is affected by the way we have structured the realization of the two states of nature.

Recall the two states are: incurring a detrimental health effect and not incurring it. By assumption, the individual must be exposed to hazardous wastes in order to face the possibility of the detrimental health effect. Thus, while the probability of state one (i.e., realizing the detrimental effect) is the joint probability of exposure and the effect, our problem structure is what has led to this outcome. It was deliberate simplification. Nonetheless this formulation is sufficiently detailed to permit an inquiry into the effects of the prospects for risk diversification for valuation measures.

Actuarially fair markets for contingent claims would require that:

$$(12) \qquad \frac{r_1}{r_2} = \frac{Rq}{(1-Rq)}$$

As a practical matter, however, given our assumption that the conditional probability of the effect given an exposure is specific to the individual, it is unlikely that this type of opportunity for risk diversification would actually be available to individuals.[12] Moreover, if we accept an ex ante perspective for treating uncertainty, then it would also be unreasonable to expect public policy measures would provide these types of opportunities for risk diversification. They would require distinguishing the opportunities for diversifying risk to suit each individual's probability of incurring a detrimental health effect given exposure to hazardous wastes. Consequently a more plausible specification for what might be the "best" public framework for diversifying risk is one that would assume the relative prices of claims corresponded to the odds of exposure to the hazardous substances as in Equation (13).

$$(13) \qquad \frac{r_1}{r_2} = \frac{R}{(1-R)}$$

The selection of a relationship between the relative prices of claims and the relative odds of states of nature does make a difference to the interpretation of the expenditure function and is the analytical counterpart to introducing different institutions (with all involving some ability to have state dependent claims). In the first case where equation (12) defines the institutions available for risk diversification $\frac{\partial E}{\partial R}$ is given by (14) below. This result is derived using the first order conditions for an expenditure minimum together with (11) and the total differential of the expected utility function evaluated at the optimum selections of claims.[13]

$$(14) \quad \frac{\partial E}{\partial R} = q(W_1^* - W_2^*) + \frac{q(V_2^* - V_1^*)}{\frac{dV_1}{dW_1}}$$

By contrast, if we assume that (13) defines the opportunities for risk diversification, then equation (15) describes an individual's valuation of a change in the exposure probability (with the bar intended to represent the difference in the optimizing values as a result of the modification in the assumptions concerning the relative prices of contingent claims).

$$(15) \quad \overline{\frac{\partial E}{\partial R}} = (\overline{W}_1 - \overline{W}_2) + \frac{(\overline{V}_2 - \overline{V}_1)}{\frac{dV_1}{dW_1}}$$

In the first case, markets tailored to the individual's circumstances will imply that the valuation reflects each individual's specific chances of incurring the detrimental effect given exposure to hazardous waste. This risk is reflected in the allocation of resources among contingent claims and diversification in response to it is feasible. By contrast, this is not the case under the second set of assumptions (i.e., equation (15)) where the insurance payments (i.e., $(\overline{W}_1 - \overline{W}_2)$ cannot be scaled to reflect the impacts of the individual specific odds of incurring the effect.

It may be argued that neither of these cases offers a plausible description of the prospects for risk diversification that are actually available to individuals. For this case an individual's valuation of changes in the probability of exposure will reflect both the pure protection benefit and the value of any improvement in the efficiency of the risk distribution of income among claims as a result of the change in this probability. This value is defined in (16) and is derived from an expenditure function defined to correspond to the case where there is no relationship between the relative prices of claims (r_1/r_2) and the relative probabilities involved.

$$(16) \qquad \frac{\partial \tilde{E}}{\partial R} = \frac{r_1(\tilde{V}_2 - \tilde{V}_1)}{R \dfrac{d\tilde{V}_1}{dW_1}}$$

where ~ indicates the optimizing values for W_1, W_2 and corresponding values of V_1 and V_2.

These three analytical descriptions of individuals' planned behavior clearly indicate that each individual's valuation of risk depends on the adjustment opportunities available to mitigate that risk. The first two cases suggest that there is a premium (for normal irreplaceable goods in Cook and Graham's [1977] terms) in addition to the insurance value of reducing the risk of a detrimental event. The distinction between the two lies in the level of the insurance that would be selected based on the terms available. The premium is based on the nature of the event at risk. In the presence of actuarially fair markets (the first case) with state independent preferences both the marginal and total utilities realized in each state of nature would be equalized. To the extent there is a difference in total utilities, even with fair markets, the model is identifying a real-world phenomena -- one state may still be preferred. The allocation of income among claims cannot compensate because at the margin the same income level will have a different value in the two states.

The third case is harder to interpret because it appears to include only the adjustment term in each of the first two cases. However, this is misleading. The value acknowledges that since there is not an efficient allocation of resources among claims both a pure protection and an efficiency effect must be reflected in the valuation.

Indeed, the increment to option price as a measure of value is quite similar to this case. Equation (17) reports the valuation of a risk change where only an option price, OP, can be paid.

$$(17) \qquad \frac{\partial E}{\partial R} = \frac{\partial OP}{\partial R} = \frac{q\ (V_2 - V_1)}{Rq\ \dfrac{dV_1}{dW_1} + (1\text{-}Rq)\ \dfrac{dV_2}{dW_2}}$$

Since mechanisms for state dependent adjustments do not exist in the option price case, the nature of the efficiency effects and pure protection benefits cannot be distinguished. Equally important, there is no mechanism that allows the individual to bring the marginal utilities of income in each state into some consistency. When there are markets for contingent claims, but relative prices do not relate the odds of the states involved, expected marginal utilities will be adjusted to reflect the signals given by these markets (or opportunities for adjustment). Clearly, this analysis suggests that the nature of the events at risk and of the opportunities for adjustment are central to the marginal valuation of risk changes.

Generalizing this framework to a case where adjustment takes place through the prices and consumption of commodities rather than in income can be accommodated, but in a more complex setting. For example, the expenditure function for the two state/two commodity case is defined by (18) below.

$$(18) \quad E(P_{11}, P_{12}, P_{21}, P_{22}; Rq; \overline{EU}) = \text{Min}\left[\sum_{i=1}^{2}\sum_{j=1}^{2} P_{ij} X_{ij} \;\middle|\; \overline{EU} = Rq\, U_1(X_{11}, X_{12}, Q) + (1-Rq)\, U_2(X_{21}, X_{22}, \overline{Q})\right]$$

where X_{ij} = contingent claim for good i, state j

P_{ij} = prices for contingent claim

Rq = probability of exposure and a detrimental health effect

To determine the valuation of risk changes in this scheme, one or more of the X_i's must be designated the commodity through which adjustment takes place. With this adjustment the properties of the expenditure function will parallel those reported earlier, but be influenced by the nature of the demand for the commodity irregardless of its use in risk diversification.

IV. IMPLICATIONS FOR MEASUREMENT

Our analysis to this point has abstracted from the problems associated with measuring individuals' valuations of risk reductions. Since it has been described in a contingent claims framework and we do not readily observe markets for contingent claims, there may appear to be little information that is of direct empirical relevance to be derived from the analysis. However, this judgement is not appropriate. There are at least three important implications for measurement:

(1) There has been an increasing tendency among resource economists to call for the use of option price as the appropriate basis for measuring the benefits associated with policies designed to change the character of the uncertainty facing individuals. Both Freeman [1984c] and Bishop [1984], for

example, acknowledge Graham's [1981] arguments for considering the fair bet point, but argue that option price is probably a reasonable "second-best" (and certainly more pragmatic) benefit concept for most policy contexts involving environmental and natural resources.

This judgement is somewhat misleading. There are two aspects of modeling individual behavior in the presence of uncertainty. One concerns a normative issue which they have implicitly addressed. That is, if we have policies that change the character of the uncertainty facing individuals, what is the most appropriate benefit concept to be used in applied welfare analyses of these actions? Graham's argument is careful to suggest the valuation implied by the fair bet point is relevant if actuarially fair markets in contingent claims exist. If they do not he suggests option price may be a reasonable second best valuation concept. What is at issue is an assumption as to whether the governmental action influences the ability to diversify risk in the way it provides (and finances) the pure protection effect of the risk reduction. This is a judgement on the set of institutions provided with or implied by the way the policy to reduce risk is implemented and paid for.

By focusing on this issue, Bishop and Freeman seem to have implicitly assumed that measurement of these values will be undertaken using survey (i.e., contingent valuation - CV) techniques. In a CV framework the analyst must describe to individuals an institutional mechanism in which the hypothetical payments are made that is consistent with the feasible public alternatives.

By contrast, our analysis has maintained that absence of contingent claims markets alone does not imply that it is infeasible for individuals to diversify risk (i.e., to arrange for payments that differ according to the state of nature). Indeed, if individuals perceive opportunities to adjust to risk, these will affect their valuation of any proposed risk reductions. Our analysis using an expected utility framework has demonstrated how changes in the perceived opportunities for adjustment affect the maximum amount individuals would plan to pay for reductions in the probability of a detrimental event.

This would imply that if contingent valuation techniques are to be used, we should not impose the "option price institution" as a part of the explanation of the valuation question. Moreover, efforts to elicit each individual's valuation of a risk reduction should be affected by how they perceive adjustment is possible to control the state-dependent payments made. While we may find that many individuals perceive the equivalent of constant payments regardless of the state of nature (i.e., the option price institution), this is an empirical question.

(2) The assumption of state-dependency of preferences suggests that the attributes of the events at risk, in addition to the direct monetary consequences, should be determinants of an individual's valuation of risk reductions. There is a substantial body of research in psychology that supports this framework. For example, in summarizing a decade of research conducted by he and his colleagues at Decision Research, Paul

Slovic [1984] recently ovbserved that two of the most important dimensions of risk for explaining individual behavior were dread and knowledge. Dread risk "...incorporates the notion that something is dread and potentially catastrophic." (p. 6) Knowledge or Known risk considers not only an individual's perception of whether the risk is known but in addition whether the effects at risk are delayed and the hazard unfamiliar. This research identified other attributes of risk that influence behavior. Slovic does not ignore them, rather his point is that these factors are especially important. He noted that:

> "...The characterization of a hazard with regard to the two factors, Dread Risk and Known Risk, will predict people's judgement as to how risky it is; however, it does not predict experts' judgement very well. The experts are relying more on actuarial statistics, the probabilities of different sizes of accidents or injuries. To an expert, that is what risk is; to a member of the public, that is what risk is not. Public perception of risk is influenced by aspects fo risk such as voluntariness, controllability, catastrophic potential, equity, and risk to future generations."(p. 6)

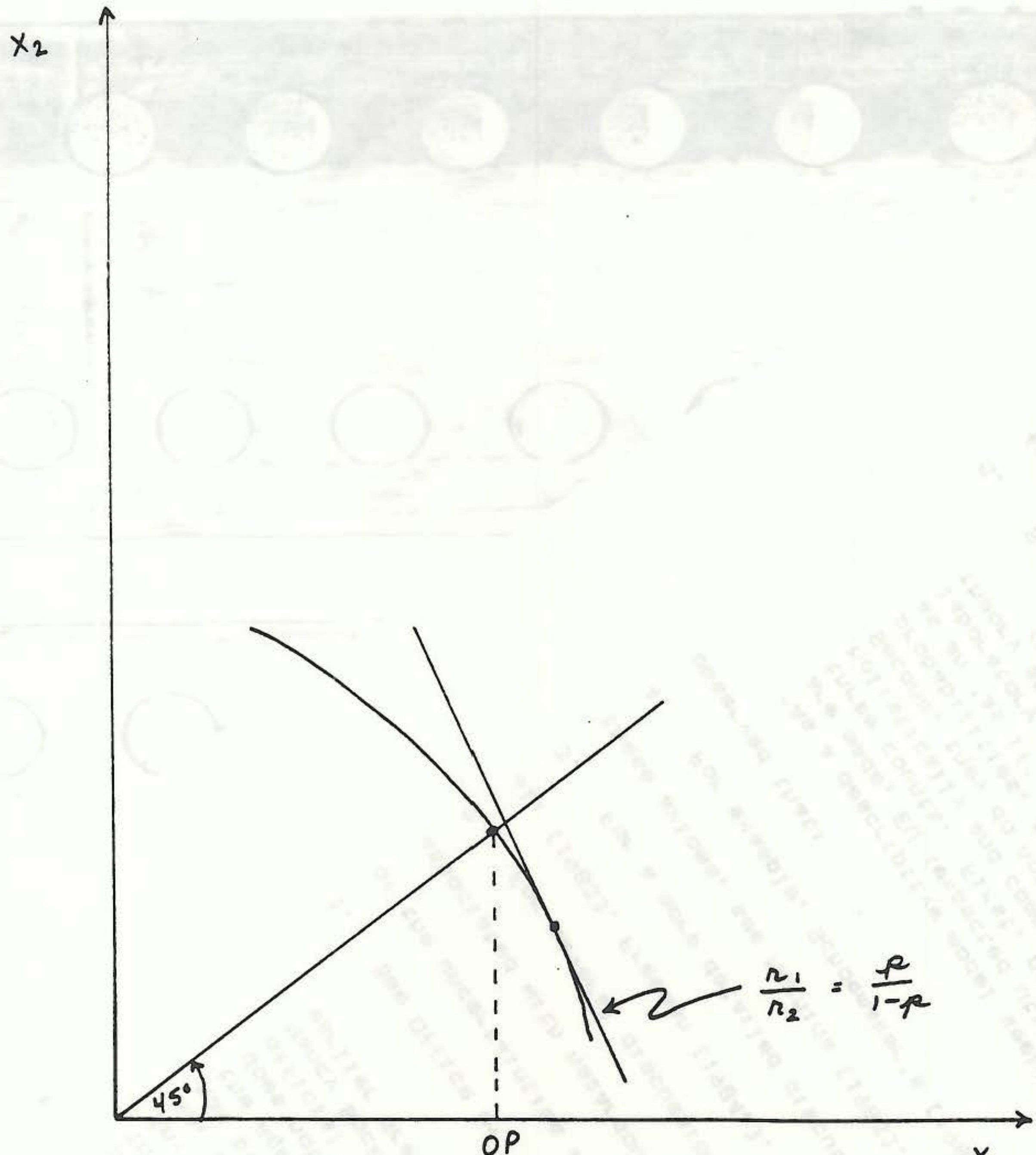
These observations are consistent with our framework and imply that contingent valuation experiments should consider circumstances with identical changes in risk levels but differences in these dimensions.

(3) Finally, conventional characterizations of risk aversion in state-independent frameworks and Karni's [1983] recent extension of them to the state-dependent case may not be relevant to understanding the valuation of risk changes. Freeman's [1984c] analysis of the size of option value uses the Arrow-Pratt measure of relative risk aversion to classify plausible degress of risk aversion. All of these measures (when interpreted in a contingent claims framework) require that risk

aversion be measured in relation to a reference point that has been defined to be the point of equality of the marginal utilities of income across states. For this condition to be realized, an individual must have access to actuarially fair markets.

Clearly the Arrow-Pratt index, defined in terms of the derivatives of the utility function (or in Karni's case by weighted averages of the index for each state-dependent utility function) can be used as an index of curvature of the function (with increasing concavity associated with risk aversion). However, the correspondence to a risk premia will depend on the assumed institutions available for adjustment. Our analysis would suggest that these values may have little relevance to the intensity of risk aversion implied by an individual's valuations of alternative risk reductions because they have been derived under an inappropriate assumption for the opportunities for adjustment to risk. Measures of the risk premia implied by an individual's degree of risk aversion must be derived with institutional assumptions that approximate the opportunities for risk diversification that are actually available.

Figure 1



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Senior Economist, Researc...
This research has been part...
Environmental Protection Age...
No. CR811075. Although the re...
has been funded in part by EPA...
the Agency's peer and administr...
does not necessarily reflect the...
official endorsement should be in...
Nancy Bockstael, Jon Conrad and Bo...
earlier drafts of this paper.

1. See Office of Technology Assessment [19...
of the uncertainties associated with evaluatin...
associated with hazardous wastes.

2. For several discussions of this taxonomy, see ...
al. [1983], Freeman [1984a], and Fisher and Raucher [...

3. For a more detailed discussion of the implications ...
these axioms, see Machina [1983].

4. For example, Schoemaker's [1982] recent review article ...
observed that:

"As a descriptive model seeking insight into ...
are made, EU (expected utility) theory fail...
three counts. First, people do not struc...
holistically and comprehensively as EU ...
Second, they do not profess informat...
probabilities, according to the E...
as an 'as if' model, poorly pr...
laboratory situations. Henc...
theory should or could ser...
(Schoemaker [1982] ...

5. See Smith [1983] f...
framework and disc...
assumption fo...
income c...

6.

of an individual's valuation of this change can be defined as follows:

$$V(Y - CS, Q_2) = V(Y, Q_1)$$

$$V(Y + ES, Q_1) = V(Y, Q_2)$$

7. Recently there has been a renewal of interest in the implications of the mechanisms available to individuals for adjustment for the definition of efficient policies for static externalities. Originally termed averting behavior by Zeckhauser and Fisher [1976], these responses have been considered in detail in two recent papers (Shibata and Winrich [1983] and Oates [1983]). State specific payments and the terms under which they can be made are somewhat analogous to the conditions affecting these static adjustments.

8. The first development of this argument appears to have been in Hartman and Plummer [1981].

9. This second assumption is a fairly restrictive simplification. While it is not essential to our arguments in what follows, it does serve to greatly simplify matters.

10. q could be a choice variable as a part of regulatory policy. One notable example of how this might take place can be found in the implementation of Section 109 of the Clean Air Act. This section mandates that primary standards for the criteria pollutants be set at a level necessary to protect public health with an adequate margin of safety. EPA has interpreted this mandate to require the definition of standards based on protecting

those individuals established to be most sensitive to each criteria pollutant (though not necessarily the most sensitive members of the group) against adverse health effects. (See Jordan, Richmond and McCurdy [1983]). This decision amounts to selecting a q as part of the regulatory process. It implicitly maintains that all other individuals have q probabilities higher than that of the sensitive group.

11. Cook and Graham [1977] developed this approach to the problem in their analysis of the demand for insurance for irreplaceable goods. See Smith [1984a] for use of their index of uniqueness in defining a bound for option value as a fraction of the expected consumer surplus.

12. This is to be distinguished from Graham's "individual risk", which he assumes can be insured against. (See Graham [1981] pp. 720-721.)

13. See Gallagher and Smith [forthcoming] for the details associated with this derivation for a simpler case.

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RISK AVERSION, INITIAL CONDITIONS, AND STATE DEPENDENT PREFERENCES

V. Kerry Smith *

1. INTRODUCTION

Over the past two decades, the Arrow [1965]-Pratt [1964] measure of local risk aversion has conditioned the way in which economists described economic behavior in the presence of uncertainty. While concavity of the individual's utility function has often been treated as synonymous with risk aversion, this index advanced our understanding of such behavior by providing a basis for ranking individuals' preferences according to the degree of aversion to risk. Moreover, this aversion can be related to the premium each risk averse individual would pay rather than accept an actuarially fair gamble.

The purpose of this paper is to suggest that two important aspects of the measure of risk aversion are overlooked in using the Arrow-Pratt format. Moreover, consideration of these issues greatly adds to the information required in judging the actual risk aversion experienced by any one individual in comparison to another.[1] The first of these considerations is the initial conditions assumed to describe an individual's circumstances when he (or she) is confronted with an actuarially fair gamble. The second relates to the opportunities that are assumed available to the individual for adjustment in response to changes in the risk experienced.

The motivation for considering these issues arises, in part, from Karni's [1983] recent extension to the literature on measuring risk aversion to accomodate state-dependent preferences. In discussing the question of defining the criteria for comparing utility functions to evaluate the degree of risk aversion, Karni observed that the issues are greatly simplified by the conventional assumption of state-independent preferences. In this case, given actuarially fair markets for contingent claims, the income, total utility, and marginal utility certainty loci are all coincident. In a state claims diagram they correspond to the 45^{o} line from the origin. Once the assumption state-independent preferences is relaxed this equality is not maintained. As a result, Karni argued that the definition of a set of reference points was especially important to the measurement of risk aversion. We shall argue, in what follows, that his identification of this point has implications that extend beyond the issue of measuring risk aversion under state-dependent preferences and relate to the conceptual basis used in defining indexes of aversion.

2. GENERALIZED MEASURES OF RISK AVERSION

An index of risk aversion should reflect three factors: the inherent reluctance of an individual to accept gambles as a result of his (or her) preferences, the risks already experienced by the individual, and the individual's ability to adjust to risk. The Arrow-Pratt measure seems to focus exclusively on the first of these factors. However, in fact, it implicitly specifies the individual's circumstances in the other two dimensions as well.[2]

This point can be demonstrated with two familiar graphs. Figure 1 presents a graphical illustration of the Arrow-Pratt index of risk aversion. It is derived by assuming the individual is on the utility certainty locus and is confronted with an actuarially fair gamble. We can define the risk premia as the constant payment that would be made in lieu of accepting the gamble. This payment is one that would equalize the expected utility from making the payment and avoiding the gamble, versus participating in the gamble and avoiding the payment. Thus, if we consider beginning the analysis at point A, where the individual has equal income, $\overline{y}$, in claims y_1 and y_2, faced with B (i.e., the prospect of a with probability p and $\frac{-pa}{1-p}$ with probability (1-p)), then the Arrow-Pratt index of risk aversion focuses on the maximum risk premia that would be paid, independent of state, to avoid B. This is defined by the expected utility equivalent of B that also lies along the income certainty locus, shown in Figure 1 as point C. This will involve a payment of $\overline{\pi}$ irregardless of the state of the world.

It should be noted that initiation of the analysis at A assumed the individual faced no other uncertainty or that actuarially fair markets in contingent claims were available to adjust to it. In either case the individual would have the reference point A. Equally important, one might also question the assumption of constant payments to avoid the gamble. This is a plausible adjustment only if the individual's utility function is state-independent and the mechanisms available for adjustment (i.e., the markets for contingent claims) are actuarially fair.

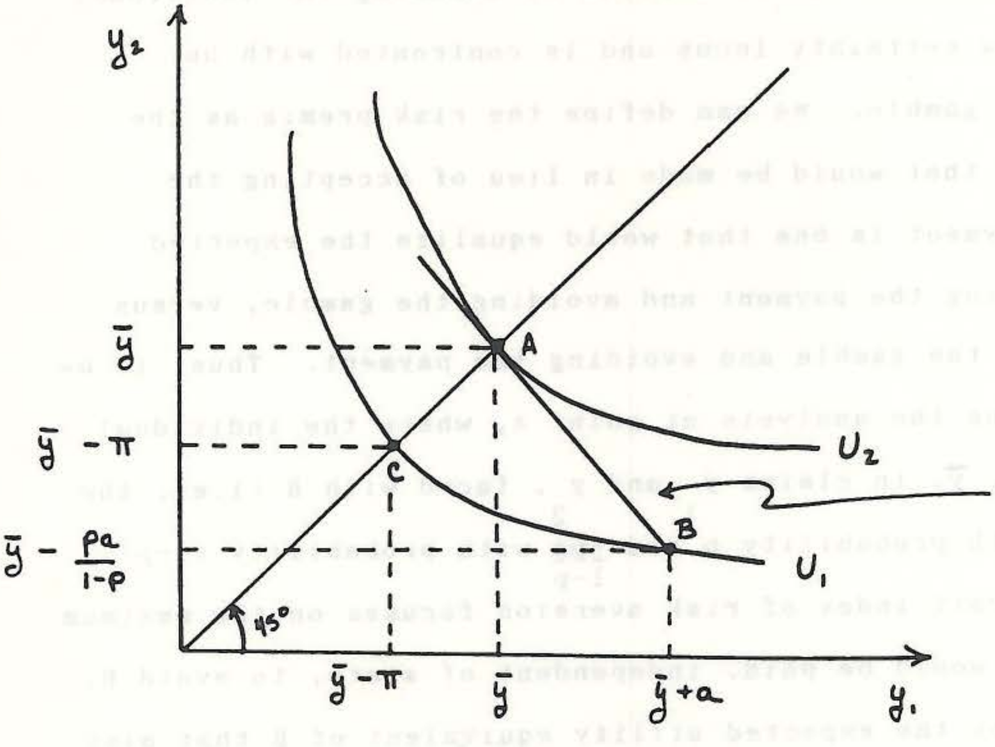

FIGURE 1

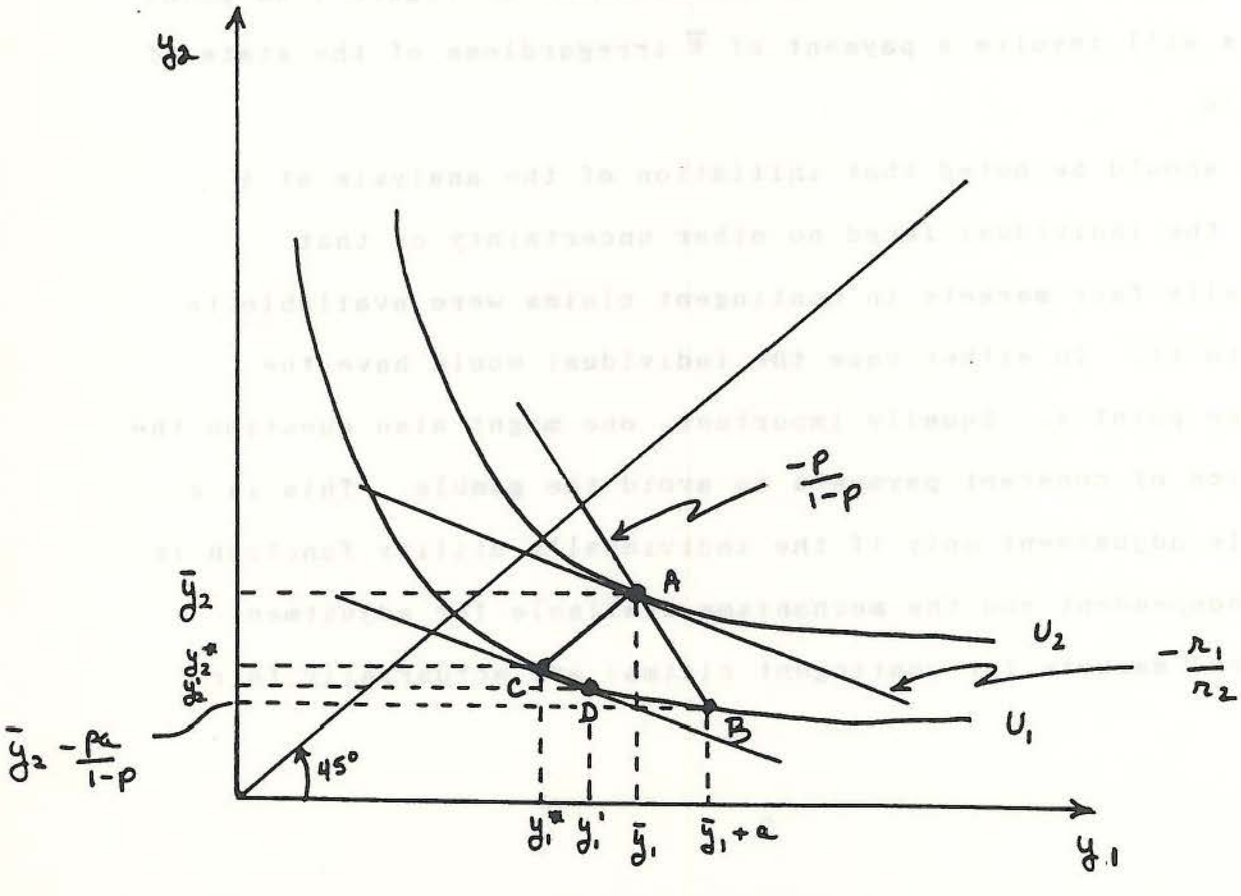

FIGURE 2

When either of these assumptions is relaxed the measure of risk premia associated with the fair gamble will not be the Arrow-Pratt formulation. Karni's analysis considered relaxation of the first of these assumptions but implicitly maintained the second by measuring risk premia along his reference set (or marginal utility certainty locus). Figure 2 illustrates the implications of the second assumption in a state-independent framework. When the individual does not face actuarially fair markets for adjustment, there is no reason to suppose that the starting point, A, (given probabilities of states 1 and 2 of p and (1-p) respectively) will lie on the 45^{o} line. Rather, it will coincide with the tangency of the budget constraint describing the nature of the available markets for contingent claims with the Von Neumann-Morgenstern indifference curve as shown in Figure 2. Given the individual faces a fair gamble starting from this reference point, the choice will be B in comparison to points that are equivalent in expected utility terms. One of these points corresponds to the case of equal payments in either state of the world and corresponds to point C (constructed by drawing a line parallel to the 45^{o} thru A) with $\pi* = \bar{y}_2 - y_2* = \bar{y}_1 - y_1*$. There is, however, no reason to prefer this index of risk aversion over one that reflects the actual adjustment to this risk the individual could make (i.e., given the relative prices of contingent claims were r_1/r_2). If D lies on the locus of tangencies of indifference curves with budget constraints with slope $-r_1/r_2$ then the risk premia corresponding to D would seem to provide a more natural measure of the risk experienced by the individual. These state dependent payments would reflect both the concavity of the individual's utility function and the nature of the institutions (markets for contingent claims) available for adjustment. The risk premia will not be constant across states (i.e., $\overline{y}_1 - y'_1 \neq \overline{y}_2 - y'_2$). Moreover, neither of the two measures that might be defined to summarize the individual's actions-- the expected payment ($p(\overline{y}_1 - y'_1) + (1-p)(\overline{y}_2 - y'_2)$) and the change in expenditures ($r_1(\overline{y}_1 - y'_1) + r_2(\overline{y}_2 - y'_2)$) expected payments defined in an Arrow-Pratt framework.

3. THE ROLE OF STATE-DEPENDENT PREFERENCES

Relaxing the assumption of state independent preferences merely strengtens these arguments, because the Arrow-Pratt measure becomes more arbitrary as an index of risk aversion in this case. As Karni acknowledged, risk premia can be measured in relation to at least three different standards -- the income certainty, utility certainty, or marginal utility certainty loci. The last is only a natural selection if the individual is assumed to face atuarially fair markets for contingent claims. If the individual faces contingent claims markets that are not actuarially fair, a more plausible measure of risk aversion would be consistent with the feasible adjustment defined by these markets.

To describe this measure analytically requires redefining the Karni reference set so that:

$$(1)\quad RRS(U) = \left\{ < y_1^*, y_2^* > \middle| U_1'(y_1^*) = K\cdot\left(\frac{1-p}{p}\right) U_2'(y_2^*) \right\}$$

where RRS = revised reference set

y_i = income level in state i

U_i = utility function for state i (with prime designating the derivative of U_i with respect to y_i)

$$K = \left(\frac{r_1}{r_2}\right)$$

The reference set under this specification is the graph of a function relating y_1^* to y_2^*. We shall designate it using the same notation as Karni as $y_1^* = g(y_2^*)$ (with $g'>0$).[3] The expected value of the risk premia, Q, associated with this reference set is given in equation (2).

$$(2) \quad Q = \left[\frac{p\, g'(y_2^*) + (1-p)}{g'(y_2^*) + (1/K)}\right]\left(\frac{K - p\,(1+K)}{(1-p)\,K}\right) X$$

$$+ \frac{1}{2}\,\frac{X^2}{(1-p)}\left(\frac{p\, g'(y_2^*) + (1-p)}{g'(y_2^*) + (1/K)}\right)\left[(1-p)\left(-\frac{U_1''(g(y_2^*))}{U_1'(g(y_2^*))}\right) + p\left(-\frac{U_2''(y_2^*)}{U_2'(y_2^*)}\right)\right.$$

where $X = y_1 - y_1^*$

There are two important distinctions between this measure and Karni's result. First, both the level and the squared deviation of the actual selection and the reference point are important to the expected risk premium. Second, the nature of contingent claims markets in comparison to the relative likelihood of the state of nature also affects the relationship between the risk premia and the curvature of each of the state-dependent utility functions.[4]

4. IMPLICATIONS

The present analysis can also be seen as a direct extension of Ross [1981] and Kihlstrom, Romer, and Williams [1981] analysis of risk aversion with random initial wealth. Both of these papers consider the conditions under which risk aversion of the utility functions imply a ranking of the risk premia with random initial wealth. The first considers the case of uncorrelated random variables (in a strong sense) and the second independent random sources of income. Our findings also relate to independent random variables, but focus on the implications of the conditions available to the individual for adjustment to the risks faced.

FOOTNOTES

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1. For an excellent discussion of the measurement of risk aversion including treatment of the strengths and weaknesses of the Arrow-Pratt measure, see Machina [1983], pp 17-22.

2. One of these points was identified by both Kihlstrom, Romer and William [1981] and Ross [1981]. Both papers were motivated by the fact that the Arrow-Pratt characterization depends on the possibility of attaining complete certainty, since the risk premium condition is the amount an individual would pay for complete insurance against a given risk. Both of these papers consider the implications of a random initial wealth for the characterization of risk aversion in response to alternative random additions to wealth.

To our knowledge, however, none of these efforts (including the more recent Dionne and Eickhoudt [1983]) has explicitly considered the implications of the circumstances available for individual adjustment together with an initially uncertain level of income.

3. Of course, our definition of the revised reference set assures that this function will be different than Karni's function, when the markets for contingent claims are not actuarially fair.

4. This will also be true in the case where the risk premia in each state are weighted by the prices of claims in those states. Under this definition the risk premium would be defined as:

$$\tilde{Q} = -\left[\frac{K + p(1+K)}{(1-p)K}\right] \chi + \frac{1}{2}\,\frac{\chi^2}{(1-p)}\ -\left[(1-p)\,\frac{U_1''\,(g\,(y_2^*)\,)}{U_1'\,(g\,(y_2^*)\,)} - p\,\frac{U_2''\,(y_2^*)}{U_2'\,(y_2^*)}\right]$$

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Part III

Contingent Valuation and Survey Methods

SOME ISSUES IN DISCRETE RESPONSE CONTINGENT VALUATION STUDIES

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I. INTRODUCTION

The use of survey or contingent valuation methods to estimate an individual's valuation of non-marketed goods, especially environmental resources, has attracted increasing attention in recent years. Initially, research efforts in this area were viewed by a majority of the economics profession with considerable skepticism. However, with the increased need for information on individuals' valuation of a whole range of environmental resources and limitations on the ability of indirect market-based methods for valuing all of these resources, there has been a substantial increase in the use of contingent valuation methods to provide this information. Indeed, a recent state-of-the-art assessment (see Cummings et al. [1984]) of the contingent valuation method (CVM) has been able to develop a set of reference operating conditions under which it was reasonable to expect the CVM approach would yield estimates with accuracy that was approximately comparable to the indirect methods. Clearly The definition of these conditions is a judgmental one. Nonetheless, it was based on a substantial number of comparative studies evaluating the relationship between CVM and indirect market estimats of the benefits associated with changes in specific environmental resources. Moreover, it does reflect the changing attitude toward the CVM approach. It is therefore particularly appropriate to consider new directions in the development of the contingent valuation method.

Michael Hanemann has provided an insightful discussion of several issues that could easily form the basis for a new line of research on refining the contingent valuation methodology. My comments on his paper focus on two generic issues raised by his discussion of the relationship between discrete response modeling and contingent valuation studies. The first of these concerns the development of models that are capable of describing how individuals will respond to a contingent valuation experiment and the use of these models in helping to understand CVM rsponses. The second is a somewhat general issue. It arises in Hanemann's discussion of extensions to the CVM methodology, and the role of maintained hypotheses in the development of benefit estimates for environmental resources. After describing each topic in the next two sections, the paper will conclude with a brief summary.

II. MODELING THE INDIVIDUAL RESPONSE PROCESS: THE ROLE OF TALKING TO A DATA POINT

One of the central questions in interpreting contingent valuation survey results concerns how the individual resopondent treats the questions that are posed to him (or her). Quite appropriately, Hanemann approaches this problem by suggesting that current research should move beyond the classification of survey biases and address the problem of modeling how individuals respond to contingent valuation questions. He suggests that CVM responses be treated as containing systematic and non-systematic components. The analysts' problem is to develop a framework that allows the systematic component to be uncovered from the overall responses. One way to recover the systematic portion of the response (which is assumed to be associated with the individual's true preferences) is to develop a formal model of individual behavior in responding to the hypothetical institutions posed by the CVM experiment.

A variety of such models have been developed in the past. Thayer [1981], for example, was the first to propose that a contingent valuation bid was the weighted average of the starting point suggested by the interviewer to the respondent along with the individual's true valuation of the resource (or the change in resource). A number of other investigators, Carson, Casterline, and Mitchell [1984] for example, have used a variety of decision rules to describe the way in which individuals might be assumed to respond to CV questions. Hanemann extends this work by proposing that a formal optimizing model be used to describe an individual's preferences. Moreover, he outlines a framework for linking that model to these CVM response decision rules in either a stochastic or a non-stochastic format. This is clearly a significant advance over the past literature because it provides an explicit behavioral explanation of an individual decision rule rather than an ad hoc description of what might be governing the process.

My principle suggestion is that such models should be based on attempts to understand how individuals interpret CVM questions. If economists are serious about the process of using survey research to understand individuals' valuation of environmental resources, then it is important to learn what other social scientists have recognized long ago. Communication with individuals is not automatic. Our terms, as well as our conception of how households will understand and adjust to an activity, may not correspond to what individuals would describe on their own. This is not to suggest that economic models of individual behavior are irrelevant, but rather to acknowledge that individuals' explanations of what they are doing may not correspond to the way we would describe their actions to them. Consequently, we need to learn to listen before we ask or model individuals' responses to CVM questions. This suggestion not only reinforces McCloskey's [1983] recent call for greater tolerance in the use questionnaires and self-descriptions, but argues that they are not limited to testing preconceived theories. If we are to avoid what he describes as "foolish inquiries" and the misuse of survey respondents, we must learn to communicate with the individuals we wish to interview. This will often mean asking them what they think we are asking for!

As the complexity of the survey research tasks and the degree of discrimination we request of individuals increases, it is especially important to discuss with potential respondents the questions we wish to ask, and how they interpret those questions. Often they can tell us how to explain the situation so as to elicit the information we want. In effect, this suggestion argues that there is a step which precedes the introduction of a formal model. It is an inductive evaluation of how individuals perceive the questions asked of them before forming their responses to a contingent valuation survey. After this step has been satisfied (and it will likely need to be satisfied in a wide array of CVM applications before it is possible to substantively improve the formal modeling of the individuals' responses), then we should be able to significantly enhance the behavioral restrictions used in decomposing individuals' responses to contingent valuation surveys.[1]

III. THE ROLE OF MAINTAINED HYPOTHESES IN BENEFIT ESTIMATION

Applied micro economic research has seen a systematic change in the way in which the behavior of economic entities, both households and firms, is described empirically. Initial empirical work in modeling household demands for goods and services and in describing firm behavior used fairly "loose" specifications of the behavioral relationships estimated in that no close ties to economic theory were offered. We have seen progressive enhancements in the practice of empirical research in both areas with fairly detailed functional forms developed as well as more attention to the criteria for selecting among them.[2] There is now been growing interest in the development of models for benefit estimation based on specific maintained hypotheses. Hanemann's proposals to develop methods for enhancing the quality of contingent valuation results are an example of this type of modeling. This approach argues (in the case of demand modeling) that the specific estimating equation should be derived, analytically, from a specific utility function and budget constraint under the assumption of constrained utility maximization.

An alternative approach would impose fewer restrictions of the function estimated, arguing instead that it is an approximation to a function that would result from the same optimization process. Without knowledge of the form for the utility function, it is implicitly argued that few restrictions should be imposed. Rather the data are presumably allowed to "tell their story." Neither approach is ideal for obvious reasons. To develop exact estimating equations that follow from the behavioral descriptions of household actions requires that simple tractable utility functions and budget constraints be used in describing the household preferences. Often these functions will impose significant structure on the nature of these demand functions. By necessity, these restrictions become a part of the maintained hypotheses used in organizing sample information and therefore in the estimation of benefits.

The alternative often relies on "high speed (but hopefully mindful) groping" to describe the nature of an individual's demand. This has been widely criticized because it has tended to completely misuse the principles of classical inference (see Wallace [1977], Leamer [1978] [1983], and Ziemer [1984] as examples). Hanemann's proposal follows the general logic of the first approach and offers an interesting adaptation for the case of CVM surveys. He argues that individuals may <u>not</u> know what their valuation of a particular environmental or natural resource might be. For example, he observes that

> "I want to suggest that, most of the time, people do not consciously <u>know</u> their preferences; they usually cannot introspect their utility functions. Instead, they discover their preferences when they actually make a choice: a decision 'pops into' their head. Their preferences are revealed to them as part of the actual choice. However,

preferences are fairly stable (there may be a random component but there also is a substantial deterministic component); therefore, if a person has faced the same choice on several previous occasions, he can estimate his own preferences with reasonable accuracy -- he can predict what he would do if the choice arose in the future -- by observing his own past actions." (p. 3)

Under these circumstances, Hanemann suggests a contingent valuation question that asks the individual to gauge whether his (or her) willingness to pay for a change in an environmental good exeeds some bound may be easier to respond to and therefore provide a more accurate response.[3] One might criticize this approach on the grounds that it is inconsistent with the estimation of valuation information. Hanemann's argument is that it need not be. The responses to such questions together with the assumption that a specific utility function describes individual's preferences will allow the analyst to recover an estimate of that individual's willingness to pay. Thus, this is a clear example of how the prior information from theory can be used to help in organizing sample responses. In this case, even though the responses are not specific willingness to pay bids, it is possible to recover estimates of these values. The maintained hypothesis of utility maximization together with the assumption of a form for the utility function and the budget constraint provides the needed supplementary information.

This seems quite sensible given our conventional models of household behavior. However, it is important to appreciate just how far we are "pushing that theory." Consider, again, the explanation that is being used to describe how the individual responds. Each individual does not know his (or her) willingness to pay for new or previously unexperienced goods or services. As a result, they are best confronted with a threshold and asked to judge how their willingness to pay relates ot it. However, economists that analyze their responses are assumed to know exactly what the nature of each individual's utility function is (up to a monotonic transformation). Otherwise, it would not be possible to recover estimates of the individual's willingness to pay. This seems to be an unreasonable set of assumptions. It remains an open question whether, even accepting the Hanemann model of the decision process, the estimation strategy involving a revised question and specific utility function will provide "better" estimates of individual valuation than questions that elicit bids used together with less restrictive prior information. This general issue can be applied to the whole line of research which begins with utility (or production) functions and attempts to derive estimating equations. It is an important and as yet unresolved issue. As Hanemann is implicitly suggesting, it may be especially important to the CVM approach to benefit estimation.

It is not sufficient to argue that the imposition of parametric utility functions insures consistency, permits extrapolation, and avoids large differences between willingness to pay and willingness to sell questions. Each of these results may be symptomatic of errors in the way in which we are modeling individual preferences or the constraints to behavior. Imposing a set of rigid maintained hypotheses to eliminate these inconsistencies does not necessarily improve the quality of the information we get as a result.

IV. SUMMARY

Hanemann's paper raises a number of important and interesting issues associated with improving the use of contingent valuation methods in benefit estimation. It will surely stimulate a wide range of research in this area. Moreover, in the process of developing his arguments, Hanemann implicitly raises an important issue for benefit estimation. That is, in the development of economic models to describe individual behavior two approaches have been used. One might be characterized as the detection of economic structure with some maintained hypotheses but relying on empirical searching of the potential models. The alternative to this approach has been to impose fairly rigid maintained hypotheses and thereby "smooth" or reduce erratic responses from a given data set. It is not clear that the latter is necessarily superior to the former. If empirical research seeks to improve the quality (in terms of both bias and precision of our estimates) and to learn how individuals make the decisions we wish to describe, some mixture of the two strategies is likely to offer a better strategy. By exposing these issues, Hanemann has offered not only a specific guide to new research in the use of the CVM approach, but has also exposed a more general set of issues concerning the approximate use of the deductive insights from economic theory and the inductive information from observing and talking to economic agents in benefit estimation.

FOOTNOTES

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1. This is an activity that economists feel uncomfortable with. Nonetheless, there is a growing recognition that this type of research is essential to the design of survey instruments. Indeed, the use of focus groups in marketing research has been a significant basis for the design and evaluation of survey research (see Bellenger et al. [1979], Axelrod [1979], and Buggie [1983].

2. For discussion of this work in production modeling, see Jorgenson [forthcoming]. A somewhat early survey of demand modeling is given in Powell [1974].

3. This follows the approach used by Bishop and Heberlein [1979] and has been discussed in detail in Hanemann [1984].

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