"The Use of Hedonic Property Value Techniques for Policy and Litigation"

by

Raymond B. Palmquist and V. Kerry Smith*

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“Everything Has a Price”

I. Introduction

Surely, an economist promoted this perspective on life. Nonetheless, if “price” is defined as the opportunity cost of a decision, few observers would debate the fact that choice in the presence of scarcity has always implied dealing with tradeoffs. There have been many efforts to quantify (in monetary terms) the tradeoffs people are willing to make and to use that information in both the policymaking process and in public litigation. This chapter focuses on applications of hedonic methods to this quantification. We will show that economic analysis has had an impact on the evaluation of environmental policy, as well as a marked effect on litigation. This view is somewhat different than the more guarded conclusions developed recently by two prominent economists. The first of these is closer to ours. Oates [2000] recently reviewed the role of economics on policy design and noted:

“…it is difficult to lay out neatly the ways in which economic research has influenced environmental policy. I can find no well-defined process of diffusion here, but there surely has been an important impact. (p.153)

Writing a little earlier, Hahn [1999] judges a less dramatic effect:

“In sum, the impact of economists on environmental policy to date has been modest. Economists can claim credit for having helped change the terms of the debate to include economic instruments – no small feat. They can also claim some credit for legislation that promotes greater balancing of costs and benefits. But specific victories of consequence are few and far between” (pp.22-23).

No economist would argue that economic criteria should be the exclusive basis for public policy decisions. Instead, most would probably suggest that economic analysis, whether of policy instruments (including incentive-based approaches) or of the net benefits of a new regulation, should have a “place at the table.” In most cases today,
it has! To be sure, at times economists are struggling to deliver useful information, but we are not in the days when economic evaluations were conducted long after policies were promulgated. Environmental economists provide a somewhat different viewpoint to policy evaluation. Consideration of the details of how economics contributes to measuring the benefits and costs of proposed policies and the indirect influence such analyses have in “feeding back” to the redesign of the policies can reveal the contributions of economists. This paper does not address all aspects of this issue. Instead, we hope to examine some specific cases where hedonic methods have been used and made a contribution and to discuss the reasons that the methods have had less impact in some other areas.

The hedonic price model is one of the most widely accepted methods for estimating the monetary tradeoffs for quality attributes of private goods and spatially delineated environmental amenities. This framework maintains that the prices of closely related heterogeneous goods are associated with measures of the attributes distinguishing those goods. A visit to the Bureau of Labor Statistics’ (BSL) web site confirms the widespread use of this logic in evaluating the prices for everything, from different hairdryers to diverse camcorders or DVD players.\(^1\) Hedonic price functions are a part of the routine quality adjustment practices of the BLS in developing cost of living indexes such as the Consumer Price Index.

The hedonic method has enjoyed wide acceptance in environmental applications as well. While most of these studies have been associated with air pollution (see Smith and Huang [1995] for a summary and meta-analysis), a range of site amenities has been studied. Hedonic theory and techniques have been widely discussed.\(^2\) With these
available summaries of the theory and practice of hedonic models, it is not clear we “need” another review of the literature.

Our focus is on how the hedonic method has been used in practice, outside the scrutiny of publication, in policy evaluations as well as in public litigation. To provide this perspective, we combine published articles along with unpublished sources – government and expert reports along with personal experience. We also include some of the “behind the scenes” stories of how hedonic modeling has been used to “price” the outputs of policy or to estimate the monetary damages of environmental injuries.

Section two provides some historical context for the diverse origins of the model. Section three provides an outline of the various property value techniques to set the stage for the rest of the chapter. Our emphasis is on benefit measurement with these models since that is the element most relevant to policy or litigation. Section four discusses how the method has been part of policy evaluations and selects two examples to describe the issues that can arise when hedonic analysis is selected to evaluate environmental policy. Section five follows a comparable strategy and selects two examples where hedonic results have been part of experts’ damage assessments in public litigation. In these profiled examples, our objective is to show how the uses and interpretation of hedonic results differ from what can be found published in studies. The sixth section describes how hedonic techniques have evolved in response to the need to study new environmental issues, and the last section provides a summary and some speculations about what is next.
II. The Context for Environmental Applications of Hedonic Methods

Hedonic price functions have been in economics for at least seventy years. Most observers credit Waugh [1929] as the first to introduce them in his Ph.D. thesis research about methods to adjust the prices of various vegetables (e.g., asparagus, tomatoes, and hothouse cucumbers) for those characteristics that were presumed to be related to quality.\(^3\) Their role in price indexes became more widely appreciated through the 1959 Stigler Commission that included in its subsequently published report Griliches’ [1961] proposal to use hedonic price indexes to adjust for quality change.\(^4\)

It took some time before this approach would be used to measure the role of positive and negative site attributes for residential locations through property markets. In the mid-1960's, before the existence of the U.S. Environmental Protection Agency and before major Federal environmental legislation, research on using property values to reveal the willingness to pay for air quality was underway, funded by federal agencies. The Division of Air Pollution in the U.S. Public Health Service supported a research effort on the costs of air pollution headed by Ronald Ridker with the assistance of several other economists.\(^5\) Arguably the most important part of that project was the property value study that provided the basis for the influential article by Ridker and Henning [1967]. This article considered the effect of air pollution on property values in St. Louis. It generated a significant literature and debate on the interpretation of the results. Despite the controversy, the idea of using real estate prices to reveal the value placed on environmental quality became firmly entrenched in the environmental economist's toolbox.\(^6\)
The use of property value studies to provide information in developing environmental policy was accepted almost from the beginning. In a report to the National Air Pollution Control Administration within the U.S. Department of Health, Education, and Welfare, Barrett and Waddell [1970] offered a status report on air pollution damages. One of the techniques they used for estimating air pollution’s cost was residential property value studies. Using estimates from four studies, they generated national annual estimates of the cost of sulfate air pollution of $5.2 billion.

In the three decades since this beginning, applications have considered almost every type of environmental problem and every geographical area. Given the number and diversity of the applications supporting use of the hedonic framework for valuing site specific amenities, one might reasonably ask whether the results have been influential. Our answer is that while they have had little direct role in designing public policy, they have been used as evidence supporting policy decisions. This distinction does not imply they have not influenced the policy debate. Environmental policy can no longer be designed without considering its full economic consequences -- both costs and benefits.

Hedonic estimates of damage have been an important method of damage appraisal for hazardous waste contamination in private litigation. Their role of public litigation seems to stand between the extremes. They are certainly more than the source for a “cross check,” but they are also less than the exclusive basis for someone to “write the check” for damages. This distinction stems, in part, from the objectives of the two types of litigation. Damage claims in private cases are made based on injuries (and resulting monetary losses) to one or more private parties as a result of the actions of another private party. For example, suppose a plant disposes of industrial residues within its own
property in a properly designed and maintained landfill. Nonetheless, there may be an accidental breach of the liner and a release of hazardous materials into the groundwater. Eventually, if undetected, the groundwater contamination can migrate to another property owner’s site and affect her ability to assure the site has a clean and safe water supply. If the causality is readily established, a private claim would focus on the diminution in the property value of this other person’s land due to the environmental problem. The focus of hedonic methods on market prices makes the monetization of this loss relatively easy to establish and understand.

The same situation would be viewed differently in public litigation where the groundwater would be interpreted as a resource held in trust for the public. Use and non-use values would need to be considered in evaluating monetary losses experienced by the public. Hedonic models would not capture the non-use values.

Because this paper is about how hedonic applications have been developed and used in these types of applications, it is important not to get ahead of our story in elaborating these conclusions. Nonetheless, some further explanation is warranted. Our conclusion for policy applications is based on distinguishing whether hedonic estimates provided the primary basis for the evaluation of gains (or losses) due to an action. As a rule, they did not. Instead, they served as a “check” (hence, the reason we used “cross check” earlier). For example, in the case of air quality, analysts would compare the benefits due to an air quality improvement that were derived by summing various types of health improvements and materials damage reductions with the benefits that were estimated using hedonic techniques. A finding that the hedonic estimate exceeded the
monetized sum of the other damage specific effects was viewed as a “plausibility check.” The opposite outcome, with a large discrepancy, was often a source of anxiety.

In the case of public litigation the role was different. The objective was to estimate the value of services lost due to injury of natural resources, and the hedonic model was viewed on the plaintiff’s side as providing a measure for a small component of the losses. For sites regarded as important to a region or a state, losses measured by the hedonic were considered a small component of the total and difficult to separate from the losses that might be subject to private litigation.

III. A Brief Overview of the Evolution Property Value Techniques

At the most basic level, a hedonic property value model is based on the premise that it is possible to establish a statistical relationship between a home’s sale price and its characteristics. These attributes include the structural features, the neighborhood characteristics, the accessibility of the location, and environmental characteristics usually delineated by location. The earliest hedonic studies used census data with tract averages for the characteristics and the average of the owners’ estimates for the property value. In the last two decades most studies have used actual sales prices for individual houses. In the early work, relying on the tract averages, initial findings were greeted with concerns about the prospects for “omitted factors” that might be the actual source of the effects attributed to approximate measures of the site disamenities. However, as the research record accumulated, these concerns have largely disappeared from the literature.

Another source of controversy and stimulus for research stems from early studies’ desire to go beyond using the estimates an indication of “concern.” Instead, users of the studies’
estimates proceeded to calculate the benefits of eliminating air pollution within a city or throughout the country. For example, almost immediately after the Ridker and Henning [1967] study was published, debate ensued about these types of conclusions based on their estimates. Soon the conceptual focus became directed to whether it was possible to infer anything about the willingness to pay for environmental quality from a hedonic regression. If so, what was revealed and under what conditions?

Fortunately, in 1974 two important papers were published that considered the theory that provided a justification for the hedonic regressions that were being estimated. Rosen [1974] continues, even today, to provide the basis for most of the environmental research on property values. An equally important, but less extensively cited paper by Freeman [1974b] raised some of the same issues, but was more concerned with addressing the issues associated with measuring willingness to pay from hedonic models. One conclusion that comes from both of these papers is that the estimated hedonic price schedule provides an estimate of the marginal willingness to pay for environmental quality for each household at the location they have chosen. Equally important, these authors suggested, and a significant amount of subsequent research further clarified, a second conclusion. In general, estimates of willingness to pay for non-marginal environmental changes or estimates of marginal willingness to pay at other locations are not available directly from the hedonic regressions.

At about the same time, Polinsky and Shavell [1976] used an urban model to analyze the conditions under which land rents could be used to infer aggregate willingness to pay. They showed that if the city was "small" (so that changes in that city did not influence prices in other cities) and "open" (so there was free in- and out-
migration), the change in aggregate land values due to an amenity change would measure aggregate willingness to pay.

As a rule, we are unwilling to assume that migration between cities is costless. Nonetheless, the logic has merit. One can use it for a given urban area. That is, Palmquist (1992a) showed that willingness to pay for non-marginal environmental changes can be derived from the hedonic regression if the environmental change is "localized" (i.e., causes the prices of some houses to change but does not change the overall hedonic equation in the city). For some types of environmental problems, such as hazardous waste sites or highway noise, this assumption of a localized impact is appropriate. The willingness to pay for non-marginal changes can be estimated by predicting the change in property values at the affected houses.14

If an externality is not localized, the hedonic equation can continue to provide some useful information. It had been known since Rosen [1974] and Freeman [1974b] that, for any given household, the prediction of the change in property value at the original house (predicted from the ex ante hedonic price equation) would be greater than the willingness to pay of that household if they stayed in the original house. However, in response to a major environmental change, there will be household relocations that make the benefit measurement more complex.15 Bartik [1988] argued that when all possible adjustments were considered, the original hedonic equation still provided an upper bound for the benefits under almost all circumstances. He also suggested reasons that the bound might be fairly tight.16

Interpreting the marginal price (i.e., partial derivative of the hedonic function with respect to a site-specific amenity or disamenity) as a benefit measure relies on a condition
describing household adjustment at the intensive margin of choice. That is, assuming a
full array of choice alternatives and costless adjustment, households will search over the
available homes until their marginal willingness to pay for increasing each attribute that
varies with location is equal to the incremental price they must pay to get it. This logic
suggests that a hedonic price function describing how prices in equilibrium vary with site
characteristics also reveals a point on the marginal willingness to pay schedule. It does
not reveal the full marginal willingness to pay schedule.

Rosen [1974] suggested a second step approach could be used to develop this
function, based on estimates of hedonic price models. Under his proposal, after
estimating the hedonic price equation, the second stage would use the point estimates of
the marginal prices to recover the underlying behavioral equations. This process is
actually more complex than his suggestion implied. Identification of the marginal
willingness to pay function requires that there be sufficient information to distinguish the
behavioral functions of individuals based on their preferences for homes and site
characteristics from both the equilibrium price schedule and the supply functions for
these characteristics. A variety of restrictions have been proposed, such as pooling
information from multiple independent markets (Palmquist [1984]) or maintaining that
household preferences follow a specific functional form with nonlinear restrictions on the
role of site amenities as influences to marginal willingness to pay (Eppe [1987],
Mendelsohn [1985], Chattapadhyay [1998]).

In the first case, independent variation in the marginal prices across different
markets serves to distinguish the marginal willingness to pay function from differences in
equilibrium conditions. In the second, the analysis assumes how marginal willingness to
pay will vary with factors that constrain household choice. The complexity and data requirements of both strategies have limited the number of examples available in the literature. As a result, it is fair to say that few of the available second stage models have had an influence on policy or litigation. There is, nonetheless, important information that would be generated in successful second stage analysis. Obviously, refined estimates of willingness to pay for non-marginal environmental changes could be important. Perhaps equally important is the fact that second stage estimates would generate information about the effect of income on the demand for environmental quality and thus the equilibrium hedonic schedule. The relationship between income and hedonic prices is important in aggregating benefit measures and in benefits transfer.

With second-stage estimates of the bid functions or demand functions, one could estimate the willingness to pay of the households that received a change in environmental quality, if there were no adjustments made, such as relocation (see Bartik [1988]). To take the adjustments into account fully would require knowledge of the hedonic price schedule after the improvement had taken place and all adjustments had been made. This would preclude ex ante benefit measurement unless one was able to use a reliable general equilibrium model to predict the new price schedule. However, even without knowledge of the new hedonic price schedule, it is possible to consider all the adjustments and develop a lower-bound estimate of the benefits (Palmquist [1988]).

A related technique that has had some impact on policy and litigation uses houses that have been sold more than once during the period being studied. If there has been an environmental change during that time and if not all the houses have experienced the change or at least not the same change, then it may be possible to use the repeat sales to
estimate the environmental effect on property values without using the hedonic characteristics of the houses.

Griliches’ work noted earlier generated interest in the use of regression techniques instead of conventional index number procedures to construct real estate price indexes. This literature developed independently from the literature on the use of hedonic models to measure the effects of amenities and also dates to the early 1960’s. In this context, Bailey, Muth, and Nourse [1963] developed a technique for using repeated sales of houses to develop a real estate price index. The objective of their study was to develop a price index to track the movement of prices for constant quality housing units over time. Thus, the prospect of basing a price index on the sales prices of the same property at different times offered the opportunity to control for quality differences that might arise by comparing different properties over time.

A second use of time can be found in work that recognized environmental variables and time may be interrelated as they would be in “event studies” in finance. The analyst then observes prices over time for a treatment group (i.e., a portion of the market area with some environmental distinction) and compares it to a control group. Nourse [1967] is an example of this type of study. It attempted to consider how an environmental problem affected the trends in the property value indexes in a study area when compared with a control. The use of study areas and control areas was well established at that time, but the technique required finding a control area, where all the real estate price effects were identical to the study area, except for the development of the environmental problem.
Palmquist [1982] showed how the environmental variable could be incorporated in the regression to avoid the need for a control area. The alternatives developed in this early literature have a direct parallel in more recent discussions of the requirements for control groups in the literature on program evaluation (see Heckman, et al. [1997]). As Palmquist noted with proper adjustment for depreciation and any modifications to a structure, a repeat sales method can help in the task of matching the conditioning variables that may influence how the treatment (i.e., area experiencing some environmental effect) affects market prices. This judgment relies on the absence of a selection effects that condition the homes with repeated sales in some way relevant to the measurement of the effect of the environmental measure (see Gatzlaff and Haurin [1997]).

Another modification of the hedonic method takes account of the fact that there is evidence that wages as well as property values are affected by environmental quality. Following Rosen [1979], Roback [1982] and Hoehn, Berger, and Blomquist [1987], among others, have combined hedonic wage and hedonic property value studies to estimate amenity values. Most of these studies have included an air pollution measure and climate measures, and some have included hazardous waste sites. These studies have assumed nationwide markets for both employment and real estate. To this point, these types of studies have not, to our knowledge, had an effect on either policy or litigation.

IV. The Use of Hedonic Studies in Policy

As we suggested at the outset, the role of property value studies in policy evaluation has been indirect, confirming that environmental problems are a source of
concern for the public. Moreover, that concern is displayed in more tangible terms than would be the case with an opinion poll that can change with developments on the evening news broadcast. People are demonstrating a willingness to pay for locations with higher levels of amenities or cleaner air. They may simply be paying to avoid the problems resulting from the pollution or to enhance the environmental amenities where they live. It does not matter. We measure their incremental values through the market revelation of these tradeoffs in the prices (and rents) for homes.

This section reviews three areas where publicly funded hedonic research has provided information to policymakers — air pollution, water pollution, and hazardous waste. In two of them (air quality and hazardous waste), we are able to use our own personal experiences to describe how and why research contributed (or failed to contribute) to the policymaking process. This is done by highlighting our two examples as “Panel” inserts and summarizing the key features in the text.

_Air_

The early research on the use of hedonic models to study air pollution developed along two lines: (a) technical guidance on how these studies should be interpreted; and (b) efforts to evaluate, in general terms, improvements in air quality. Both lines of research were not tied to a specific regulation. However, the second category did contribute to the general motivation for air pollution policy.

As noted earlier, the first environmental property value study was done as part of a research project funded by the U.S. Public Health Service (see Ridker [1967]). It sought to contribute to both lines of inquiry. An early example relevant to evaluating air pollution policy was Barrett and Waddell’s [1970] report to the National Air Pollution
Control Administration. It surveyed eight categories of damages and developed estimates of damages for health, materials, vegetation, and residential property values. They concluded that "(t)he property value approach ... has provided the soundest basis for estimating pollution costs." By 1974 Waddell released a similar report, although by then it was a report to the U.S. Environmental Protection Agency, and the number of property value studies increased from four to ten.

Another early example focused on developing guidance was the 1974 "The Costs and Benefits of Automobile Emission Control," issued as volume 4 of "Air Quality and Automobile Emission Control" by the National Academy of Science and the National Academy of Engineering. Chapter IV was on "Economic Benefits of Air Quality Data as Estimated from Market Data." It contained research that would later appear in Polinsky and Shavell [1976] and Polinsky and Rubinfeld [1977], and research by Harrison that foreshadowed Harrison and Rubinfeld [1978]. It also provided some early theoretical guidance to the measurement of benefits from property value studies.

The focus of property value research changed in the early 1980’s during the development of evaluations for EPA’s proposed secondary standards for sulfur dioxide and total suspended particulates. Mathtech [1981], under contract to the EPA, did the benefit analysis. This work provides the basis for our first panel summary of research that has not found its way into the mainstream of the published literature in environmental economics. We devote specific attention to it here because, despite the fact that twenty years has elapsed since it was finished, the results are still in use today!23

This particular set of research was organized in Allen Basala’s Benefit Analysis Program. It was conducted by a variety of consulting firms and we were retained as
outside reviewers for the research throughout its development. As a result, we can provide insiders’ perspectives on the work. Economists at Mathtech (primarily Drs. Robert Horst and Ernest Manuel) conducted original research on the effects of air pollution on households and firms. In the first set of work (for households) their analysis considered how individuals reallocate their budgets in response to changes in air pollution. The logic of their analysis followed the linear expenditure system, which was frequently used at that time to estimate the full set of consumer demand parameters. The application of the logic for measuring the contribution of amenities had been pioneered by Shapiro and Smith [1981], but that analysis had not attempted a full scale application to commodities, such as cleaning services, likely to be impacted by a change in air pollution.

This strategy was selected because the original objective was to measure what EPA had labeled the benefits due to the secondary standards for the criteria pollutants. These secondary benefits were non-health-related because the primary standards were to “eliminate” any damages people might experience due to health effects. Thus, this approach, by relating levels of air pollution to specific commodities, permitted the isolation of the non-health consequences.

Previously estimated property value studies were essential because the household method was new to everyone. It relied on using the expenditure data for specific types of commodities to reveal a seemingly weak “signal” of the effects on household adjustments. As a result, it was argued that the hedonic model’s upper bound could be relied upon to reflect the more complete adjustment a household would make to improve the air quality conditions they experienced. Estimates of the incremental change in the
annualized housing price could be developed for each city and compared with measures of benefits from reductions in air pollution in that city, based on the expenditure model. It then offered a “cross check” of the plausibility of the Mathtech model’s results. Using the theoretical developments of Rosen and Freeman, the Mathtech economists interpreted the results of existing studies to define this upper bound. There were eleven hedonic studies that were judged appropriate, and benefit measures were developed from them to compare with estimates from the expenditure model for alternative secondary standards.

Mathtech was to measure the avoided losses from reductions in soiling and materials damage. These were the main non-health or, what the legislation referred to as, “welfare effects” from the policy. These measures were to provide the basis of the secondary national ambient standards. The household model estimates the non-health damages associated with air pollution by linking pollution measures to the minimum or threshold expenditures a household was hypothesized to undertake in activities associated with cleaning or materials damage. The preference specification in the model was a Stone-Geary utility function. This formulation is often interpreted as implying some threshold level of consumption that is an estimated parameter for each category of expenditures. This threshold amount must be consumed before there is a positive contribution to utility. By hypothesizing air pollution increased these thresholds their model targeted the non-health effects. Four aggregate categories were targeted in the model: shelter (including home repair and utilities); home operations (including laundry and cleaning); furnishings and equipment; and transportation. Both sulfur dioxide and total suspended particulates were considered to potentially affect these expenditures.

Hedonic estimates of the incremental benefits from reduced air pollution were assumed to
reflect all the related gains for an equivalent reduction in air pollution. Thus, in principle, they should be larger. They would include expenditures households would be willing to make to avoid health impacts and other aesthetic effects that were omitted from the expenditure model.

Table 1 below summarizes the per household (in 1980 dollars) benefits measure for TSP and secondary standards. The model’s estimates of benefits from meeting the secondary standard at the household level were recognized as incomplete. The model would not reflect aesthetic dimensions (e.g., enhanced visibility) of reduction in air pollution or any additional health related gain experienced by households from improvements beyond the primary standard.

Comparing these benefit measures to those derived using a linear approximation from a hedonic property value model should have a clear inequality. That is, we expect the hedonic estimates (e.g., marginal willingness to pay times the change in the relevant air pollutant) to exceed those from the household model. This inequality follows from both the fact that the approximation from is generally an upper-bound and from the fact that we would expect the hedonic to capture more sources of benefits from air pollution reductions.

At one level, this is not an especially demanding plausibility check. It is difficult to specify, without further detailed assumptions, how much of a difference to expect. As a result, some observers have suggested these types of comparisons add little to the policy analysis. We believe this argument misses a more fundamental aspect of the comparison. Each model uses quite different economic data and describes, at very different levels, how air pollution affects behavior. Yet, when the results are evaluated,
the benefit measures follow the ordering that we expect and they are in a plausible range in relation to household income. This is not a discriminating test at one level, but it is a general endorsement for the logic underlying the fact that there are behavioral responses to air pollution and that we can use them to estimate benefits.

Table 1: Mathtech Secondary Benefit Analysis – Household versus Hedonic Analysis

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Household Model</th>
<th>Hedonic Cross Check*</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSP</td>
<td>$16.25</td>
<td>$120.00 – 289.00</td>
</tr>
<tr>
<td>SO₂</td>
<td>$16.50</td>
<td>$48.00 - 69.00</td>
</tr>
</tbody>
</table>

* These estimates were derived by evaluating the most likely property value/air pollution elasticities from past literature. The Mathtech study reports the likely range for sulfur dioxide as –0.07 to –0.10 and –0.05 to –0.12 for TSP. The measures for ambient concentrations were expressed in terms of the average of the second high values.

Two years later, as part of Mathtech [1983], the same economists did a similar study of alternative primary standards for particular matter, including a move to a new format for measuring particulate matter and defining the standard. The change was from total suspended particular matter to one based on small particles (10 microns or less), PM10. This second set of activities provides the information for Panel 1.

When the scope of the regulatory analysis was expanded to consider a new primary standard for these pollutants, all the health and the welfare effects of a new standard could be considered. In this case, the hedonic estimates should serve as a more
discriminating cross check, because the categories of benefits now considered were more complete and, thus, much closer to the full range of issues assumed to be considered influences to property values. Indeed, the issue of double counting was identified as a clear possibility as the various effects were separately estimated and then simply added together.

Panel 1 summarizes the aggregate analysis. Aggregation procedure A limited consideration of morbidity studies to those reviewed as part of the development of EPA’s Criteria Document for the standard. It omitted some morbidity effects, because the health effects were regarded as not reliably measured. Procedure C includes these effects, along with measures of the benefits from soiling and materials effects.

The panel illustrates one of the difficulties with relying on the first stage of the hedonic model. We know, in advance, that using the marginal WTP from the hedonic model as a “price” for pollution improvement is incorrect. We also know that there will be double counting when we add across categories of benefits from other benefit measurement strategies, as if they are independent. Given the potential errors in the same direction with both estimation strategies, it is not possible to predict unambiguously their relationship.

Our conclusion, as reviewers of the Mathtech study, could not, as a result, be especially discriminating. Rather, we were forced to focus on the “glass half-full” dimensions of the findings. That is, as we noted earlier, these largely independent strategies came to estimates that were within the same “order of magnitude” (e.g., comparing aggregation procedure C with the midpoint and maximum of the hedonic
results). As such, it offered a broad-based confirmation of the plausibility of behavioral responses to air pollutants that partially reflect the health consequences of pollution and, as a result, provide an approximate estimate of the benefits.

Because the standard was motivated by health concerns, no one involved in the process, and especially not the health scientists involved in the risk assessments that lead to the standards, was prepared to accept the assumption that the hedonic “magically” reflected all of these concerns. It was accepted as a "cross check" based on the revealed “actual” spending decisions of households!

About this same time, the EPA was also funding important work by Brookshire, et al. (1982a) on benefits measurement. The main thrust of that research was advancing contingent valuation methods. However, as part of the project they developed a hedonic property value study of air pollution in the South Coast Air Basin surrounding Los Angeles. They were using the established hedonic method as a comparable type of “cross check” on the newer contingent valuation method. This was Appendix A of the report and became Brookshire, et al. [1982b]. However, in this case the check was on a new method and not an attempt to construct composite estimates of the benefits from a policy.25

Clearly, the opportunities to observe a multiplicity of household choices – all motivated by a desire to obtain improved air quality – was recognized. What evolved from the process, ultimately, were the joint estimation strategies we now take for granted. The logic of “cross checks” initiated in the early Mathtech comparisons and independently used by Brookshire, et al. to evaluate contingent valuation estimates were rudimentary steps in a process that was taken to a new level in Cameron’s [1992]
breakthrough article proposing a joint estimator combining revealed preference and contingent valuation estimates for recreation demand. It is clear is that the logic was being used prior to her paper in a range of different ways – including this “cross check” role for the hedonic.

**Visibility**

Basala’s program also lead efforts to introduce benefit measures for visibility effects on Class I (or pristine) areas. The program contracted with Rowe and Chestnut [1981] to develop the *Visibility Benefits Assessment Guidebook*. While the guidebook emphasized survey methods, it also discussed the use of property value studies to estimate willingness to pay for visibility. The desire to use more than one method and provide plausibility checks through comparison was clearly a part of the recommendations. Most of the early visibility studies were at recreation areas in the west, so estimates from hedonic methods were not well adapted to address the issues involved. However, there was recognition that hedonic models could serve as cross checks in this context. This lead EPA to contract for a study of visibility in the eastern United States, and Tolley, et al. [1986] did use hedonic techniques as one part of the research.

This hedonic research was headed by Glenn Blomquist and sought to value “view oriented” amenities and compare the values to those derived by contingent valuation methods. While visibility was the purpose of the research, the hedonic effort considered “views” rather than visibility. The comparison of hedonic and contingent valuation results for “views” was then used as partial justification for relying on the latter for visibility estimates. The data came from “view-oriented” residences near the shore of
Lake Michigan in Chicago. They interviewed residents of ten high-rise buildings, obtaining 208 responses. They asked three contingent valuation questions about a view of the lake and the height of the unit in the building. They also obtained information on the characteristics of the unit and monthly housing expenditure from the survey. For the most part, the comparison of hedonic and contingent valuation methods was as expected. The willingness to pay for a lake view by those that had a lake view exceeded the increase in market rent for a lake view. The willingness to pay to be on a higher floor was less than the increase in equilibrium rent to live on the higher floor, as one would expect since the residents had not chosen to live on the higher floor.

An anomalous result from the study was that those without a lake view said they would be willing to pay more to get the lake view than the hedonic results said they would have to pay for the view, implying they should have moved and be enjoying the views. This result could have been a reflection of incomplete information available to existing renters about the premium required for a view. Overall, since the study obtained the expected results in all cases but this last one, the authors interpreted their overall findings as support for the survey methods, which they then used to value improvements in visibility.

**Water Pollution**

One of the earliest property value studies funded by the U.S. Environmental Protection Agency was for water pollution control (Dornbusch and Barrager [1973]). Their study identified areas that experienced a significant change in water quality between 1960 and 1970. This strategy was comparable to efforts initiated for air pollution by Nourse [1967] to define environmental events and use hedonic methods to
estimate their effects on people’s willingness to pay. Dornbusch and Barrager included both residential and recreational areas in their selection process. Their final choices were six sites on four rivers.\textsuperscript{27} One of the sites was rural, while the others were in developed areas. They used actual sales in the later period. These were linked to an adjusted assessed value at the earlier time. The adjustment was based on the average ratio of assessed value to market value. They regressed the change in property values from before to after a water quality change on the initial value of the house, other (non-water quality) changes that took place in the area, and distance from the water body. In addition to this absolute property value change, they estimated a percentage change model. They interpreted the changes in property values on the river as being attributable to the water quality improvement. For houses located back from the rivers, the regressions suggested that the appreciation was reduced with distance from the river, but the water quality improvement had effects as far as 4,000 feet back from the river. The regressions were considered successful in only four of the six study areas. As with other early studies, the results from the few study areas were used to generate national estimates of water pollution damages, although with a number of caveats.

Today it would be easy to point out shortcomings with the Dornbusch and Barrager study, but as an early hedonic study it was thoughtfully done. Moreover, the problems they encountered also help to explain the relative paucity of hedonic models using water quality. The residential effects of water quality only extend back from the water body a short distance, which limits the areas that can be considered. There are no objectively measurable effects of the water quality that vary with distance. Proximity to water can be desirable or undesirable depending on the condition of the water body. At
any particular time there is likely to be relatively little variation in the water quality experienced by different houses in a single market area. This feature differs sharply from air pollutants, etc. Thus, one has to use water quality changes over time, but to do so requires a relatively clear basis for controlling how other factors influenced property values during the time period being studied. This point is another reflection of the “event study” feature that is implicit in the design of some hedonic studies involving environmental amenities. We return to this issue in our second Panel on the use of hedonic models in hazardous waste policy evaluations. All of these reasons may account for the paucity of government-funded hedonic water quality studies.

**Transportation Noise**

The effect of disamenities, particularly noise, from transportation facilities on surrounding property values has been a concern since the 1960's. By the early 1970's government agencies were funding studies using what would become known as hedonic techniques. The Federal Highway Administration (FHWA) within the U.S. Department of Transportation funded many of the studies that focused on highway noise. Because of the nature of the externality involved, these studies were some of the first to use disaggregate data.

While there were limited studies on highway noise and property values (Colony [1966], [1967]; Towne [1966]; Brinton and Bloom [1969]) prior to Gamble, et al. [1973], this was the first major study funded by FHWA. They considered both beneficial and adverse effects from Interstate highways in four communities in New Jersey, Virginia, and Maryland. The areas were selected primarily to analyze the adverse effects of both noise and air pollution. They had some information on the characteristics of the houses
and the occupants, although some important variables such as square feet of living space were not available. They used stepwise regression techniques to arrive at “final” specifications. Because of this strategy for model specification, the model for one area had only two independent variables other than noise while another had seven. Ideally, one would like to be able to compare the effects of the noise variable with approximately comparable specifications. There were also a limited number of observations with noise levels above ambient conditions in two of the areas. In spite of these problems, the noise variable’s estimated coefficient was consistently negative and had a plausible value (in terms of overall magnitude) in all the areas. In addition to the hedonic-type regression, as part of this study Langley [1976] compared real estate price indexes next to the highway and further back using the Bailey, Muth, and Nourse technique. He found that houses next to the highway appreciate more slowly, although there were some problems with his interpretation.

Nelson [1975], in the next major study, attempted to distinguish the hedonic equation and the demand curves for environmental quality of both air pollution and noise. Unfortunately, rather than using data on individual sales, Nelson used census tract data. Census data would be subject to the shortcomings discussed for air quality above, but there is a further problem with using it with highway noise. Noise effects are quite localized and cover an area much smaller than a census tract. A noise prediction program was used for each census tract, but even if it provided an accurate measure (which was unlikely), that measure would represent an average of the noise near and further back from the highway. Similarly, the owner estimated property values would be an average of properties with and without highway noise. Thus, we might expect little ability to
detect an effect for noise. Nonetheless, Nelson's estimates were very close to those of Gamble, et al.

One of us (Palmquist) initiated his long-standing interest in hedonics through an FHWA funded research project. In Palmquist [1980] it was possible to use much better data to consider the link between highway noise and property values. In each of three areas bordering Interstate highways in Washington State, data on a large number of sales of individual houses were collected, and extensive noise monitoring was also done. The three areas represented three different types of neighborhoods that could be classified as upper-middle class, lower-middle class, and lower class. As expected, the effects of highway noise increased with the average income in the neighborhoods.32

Related research has been conducted in Canada. The Ontario Ministry of the Environment supported Hall, et al. [1978]. They used areas where there were rows of houses parallel to a highway to assist with the noise monitoring and where the houses were fairly homogeneous. They did include some of the major characteristics of the houses to control for differences. They found that in an area with a high noise level, property values next to the highway were discounted, but in areas with more moderate noise levels this was not true. A follow-on study using a large data set (Taylor, et al. [1982]) found a significant noise discount for both arterial and expressway sites.

Surprisingly, few of the studies of airport noise have been sponsored by government agencies, so they will not be covered in much detail here.33 It is worth noting that a majority of the airport noise studies have used census data. However, with airplane noise, wide areas experience comparable noise levels so the problems identified for highway studies with accurately gauging the noise level do not arise. Census data in this
case are not subject to the problem of being too aggregated to capture the effect. An interesting study of airport noise using both disaggregate and aggregate data (O'Byrne, et al. [1985]) obtained comparable results with the alternative data sources.

**Hazardous Wastes**

The Superfund legislation (CERCLA in 1980 and RCRA in 1983) raised the profile of studies evaluating the economic consequences of land disposal of hazardous substances. The U.S. Environmental Protection Agency funded the first major study on this topic, Adler, et al. [1982]. As in the Dornbusch and Barrager [1973] study, the work accepts the premise that site selection must be used as a means to establish control over the additional influences on the property values. This was considered key to measuring the amenity or disamenity effects. In the Adler, et al. study, the researchers screened 150 sites and selected two as being promising for further analysis. They sought relatively homogeneous areas that were primarily residential and had no other major sources of disamenities. They also wanted the hazards of the site to be known to the public. Finally, adequate data had to be available. The overall requirements implied that the analyses were *retrospective* studies, where it was possible to characterize contamination as an event, and evaluate the effects on property values once it was recognized.

It is interesting to note that the hedonic analysis can become an event that may influence property values! That is, a detailed analysis of how current property values have been influenced by a contamination episode from an existing waste site might be interpreted as a signal that public action was about to take place. We expect that asset prices would reflect new information about conditions that impact the services provided by those assets in the future and a cleanup of the site might lead to a change in those
services. Thus, we might expect knowledge that the analysis was taking place would influence subsequent sale prices in the area, perhaps making it difficult to replicate the negative effects of the existing waste site. That is, if households’ expectations were that the cleanup would be successful, then one might argue this would reduce the likelihood of capturing the negative effects of the disposal site in subsequent studies.

This concern is not speculation. It was, in fact, a key consideration in the decisions about how to report and use hedonic results that were part of a Regulatory Impact Analysis (RIA). This occupied a substantial amount of the attention of the Environmental Economics Committee of EPA’s Science Advisory Board when one of us (Smith) co-chaired this committee. We return to it below as part of describing our second policy panel.

For now, considering Adler, et al., by all measures it was regarded as reasonably successful. However, to our knowledge, it was never published and is rarely cited in the hedonic literature on the effects of hazardous waste sites. The authors were able to develop a fairly complete specification of housing characteristics in both locations (Andover, Minnesota and Pleasant Plains, NJ). They used dummy variables for quarter-mile rings up to 2-1/2 miles from dumpsites in some specifications, and distance gradients in others.

The nature of the environmental problems differed at the two sites that were used. The first (Pleasant Plains, NJ) was a case of illegal dumping of benzene, ketones, etc. during 1971, which resulted in groundwater contamination. About 1974 the problem was discovered and quick action taken, including closing of wells used for some of the water supply, extending wells deeper to an uncontaminated aquifer, and providing municipal
water. In this area there was fairly clear evidence that property values generally increased with distance from the site once the problem was known. Sales prior to the dumping did not show the same trend.

The second site (Andover, MN) included a waste site with somewhat less toxic wastes and a landfill that received some hazardous wastes in the distant past and where the lining was beginning to deteriorate. However, there was little contamination at the time of the study, even though there was a future threat. There was no evidence that property values were reduced near either of the sites. Since both sites had been used for a long time, there was no opportunity for a before and after comparison. While hedonic techniques have been refined in the years since these studies were done, the results in both areas seem plausible.

After the Adler, et al. study, the EPA funded a series of additional studies of the effects of hazardous waste sites on property values. Harrison and Stock [1985] identified two important issues that had not received much consideration in the Adler, et al. study. When there are multiple hazardous waste sites in a given housing market, how does one characterize the disamenity effects? When information about a hazard is made available, what effect does this have on property values? The former issue has not been addressed much in later research. Michaels and Smith [1990] used the Harrison and Stock data to investigate the definition of the extent of the housing market for hedonic price functions. Stock [1991] proposed nonparametric kernel estimates for evaluating hedonic price functions with hedonic data. However, neither study addressed the multiple site/distance issue identified in the initial unpublished effort.34
In some respects, this issue is similar to a current issue in hedonic modeling of the value of open space and distribution of public and private land uses that contribute to this positive externality. An important issue raised by Bockstael and Irwin [2000] in that context is the endogeneity in some of the land use measures, reflecting proxies for amenity effects and other attributes that are relevant to competing demands for the sites involved.

The second effort funded by EPA, Schulze, et al. [1986], used both survey and property value methods. This study sought to apply the insights of economics and psychology to evaluate people's reactions to the risks posed by living near hazardous waste sites. They selected three sites that were in homogeneous, populated areas, where the disamenity was clearly perceived. The first area was a large landfill where the build-up of methane gas had caused an evacuation of nearby residents. There were odors and some contamination of groundwater off-site but no contaminated wells at that time. There was some vinyl chloride on the site. They ran hedonic specifications using, in turn, proximity to the site (within 1,000 feet), the inverse of distance from the site, and these variables combined with variables that incorporated the timing of the evacuation of home near the site. All of the coefficients implied negative effects for proximity and were significant. The magnitude of the damages was much greater than that implied by the objective health risks.

The second site was also a landfill with both hazardous and municipal wastes. There was methane build-up but no evacuation. At the time of their analysis, the site had been recently closed. The estimates were not as significant as in the first location, although they were larger in magnitude. Within 1000 feet of the site there was a negative
effect, and if anything, closing the site raised concerns. For this second site, the researchers also combined survey results on residents’ subjective risk perceptions with the property value data. For a series of small areas around the site, they assigned the average risk ranking given by residents in that area. Based on these subjective risks, closing the landfill increased property values by an average of $5,000, but the proximity of the site still reduced the value by about $4,800. These results are also reported in McClelland, et al. [1990].

The third site was not as well suited for this type of study, and the results were inconclusive. The bottom line conclusion to be drawn from these three case studies is the difficulty in characterizing how landfills posing hazards are perceived by consumers. The specific details of each situation seem to preclude broad generalizations about the effectiveness of distance based measures for the perceived risk in all cases. Equally important, they support our observation that a hedonic analysis, conducted in a policy context, can itself become an “event” that triggers a market response.

In October 1992, EPA issued several draft studies intended to be used in Regulatory Impact Analysis for the Corrective Action Rule for RCRA sites that had accidentally leaked or released hazardous substances. An important part of one of the studies involved the use of a contingent valuation survey to estimate the nonuse benefits from the site cleanups envisioned under the rule. The evaluation was very high profile for a number of reasons. Foremost among them was the controversy about contingent valuation that was dominant in discussions of researchers involved in non-market valuation. The Exxon sponsored Symposium on Contingent Valuation had earlier (April 1992) raised issues with the method (see Hausman [1993] for the published versions of
the papers presented at that symposium). This study reported one of the largest publicly available contingent valuation (CV) surveys at the time. As a result, most of the evaluation of the RIA focused on the CV effort.

What has been largely overlooked from the economic analysis in the RIA is a detailed hedonic study of the effects of events involving releases of hazardous substances from these sites on residential property values near the sites. Greg Michaels of Abt Associates, (and of the Michaels and Smith [1990] paper described earlier), conducted the hedonic analysis. It considered each of three sites and sought to use them in the evaluation of the benefits from the proposed rule. Panel 2 provides a summary of the hedonic property value analysis for one of the three treatment, storage, and disposal facilities (TSDF). This specific study of properties around what was identified as facility #1, was included in the draft RIA, and benefit measures were computed based on the estimates. Very short summaries of the estimated values (based on the increased property values) of the one-mile intervention scenarios for the other two sites were included in the RIA.

_______________INSERT PANEL 2 ABOUT HERE_______________

Several aspects of this analysis are important to our example. First, the facilities were never identified in the benefit analysis for the RIA. In all supporting documents, the names and identifying information were redacted. The reason was direct. As we noted, the policy analysts recognized that the decision to undertake the analysis of these specific aspects offered the prospects of “creating an event” that had the potential of having short-term influence on property values. As noted earlier, the policy analysts
involved (and presumably EPA’s lawyers) were concerned it could be interpreted as signaling to private homeowners that corrective action would be undertaken.

Second, the analysis did not attempt to identify how the specific facilities related to the set of all TSDF’s likely to be covered by the corrective action rule. The draft report noted that:

The property value results may contribute to an improved understanding of the economic damages impacted by TSDF’s, but the analysis should be viewed as a work-in-progress…They derive from housing market behavior at three TSDF’s only and are not intended to represent the entire universe of TSDF’s (p.11-18).

The section on hedonic models concludes noting that the range of benefits estimated in these cases is likely to encompass benefits experienced at TSDF’s.

Finally, the analysis, as identified in the panel, indirectly isolated an issue with the hedonic approach. The policy must be converted into the format used to capture the effects of the undesirable facility. All of the hedonic studies for the effects of hazardous facilities have used some function of distance. To gauge the marginal benefits from a policy, the analyst must define the policy’s anticipated effects in terms of some change in the distance measure used in the hedonic function. When the hedonic study is done evaluating a site-specific amenity, like air pollution or noise, the environmental variable is measured in units of pollution. The translation to a measure of the marginal benefits for an environmental improvement is reasonably straightforward. For hedonic studies of hazardous waste sites that use distance as a proxy for the site specific environmental attribute, defining the benefits of a cleanup is more complex. Unless the site is completely cleaned up and there are no residual effects on property values, it is necessary
to translate the actual reduction in perceived risk at a given site into an effective increase in distance from the site.\textsuperscript{35}

Panel 2 shows how the sample analysis for facility I interprets the corrective action rule as equivalent to moving each house different distance increments away from the facility. The definition of these distance increments is the way that the policy is translated into terms consistent with the estimated model. The study also considered a policy alternative as the equivalent to returning to the pre-event conditions. The overall benefits from each interpretation of the policy are quite different. With the policy treated as equivalent to a reversal of the events associated with contamination to the pre-event conditions, the hedonic model yields aggregate benefit estimates for the homes around facility I that are twenty times larger than in the case of a distance increment of four miles. Thus, it is possible to have a dramatic effect on the benefits attributed to policy through the process used to link the results of the policy to the proxy variables characterizing how the negative effects of a hazardous waste site influence private properties.\textsuperscript{36} As research in hedonic models has expanded to consider a wider range of site specific amenities and disamenities, experience is growing in how to address these issues. Nonetheless, we are not at a stage where it is possible to prescribe answers to the issues implicitly raised in this RIA’s evaluation of cleanup alternatives. The logic stemming from the cross-check use of hedonics may offer an approach to accelerate the learning process. There is no reason why the Cameron joint estimation logic could not be applied using a hedonic framework. By focusing a stated preference study on the relationship between distance to landfills (as well as other proxies) and an individual’s perceived risk or disamenity and then estimating the risk perception model jointly with a
behavioral model consistent with the hedonic framework, it may be possible to test the logic that has been used to represent policies.\textsuperscript{37}

V. The Use of Hedonic Studies in Litigation

Property value studies have also been used in litigation. We distinguished two types of litigation: (a) public litigation where some designated agent becomes the trustee for a public interest and seeks compensation under a liability statute (b) private litigation where individuals bring civil law suits under the common law or a private liability statute. The most visible examples where hedonic models have been used in litigation are those pursued under a liability statute that involves a public interest. However, even in these cases the exact record of the analysis undertaken is often not readily available. The majority of the cases have been settled before they go to court and the record can be sealed as a condition of settlement.

To illustrate how hedonic models can be used in different ways in these settings we relied on the information available to us from one or another form of participation in the process involving public litigation.\textsuperscript{38} There is no specific discussion of uses of hedonic methods in private litigation. We identified these potential applications because the use of hedonic methods, especially in activities associated with site specific disamenities associated with hazardous waste has evolved to the point where pragmatic guidance is now routinely published in practitioner journals (see Patchin [1994] and Roddewig [1996] as examples). Thus, our summary will not represent the full extent of uses that have been made of hedonic models in litigation.
Most of the public litigation involving residential properties and liability for environmental effects stems from the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, its amendments, and the Oil Pollution Act (OPA) of 1990. Natural Resource Damage Assessments (NRDA) under these statutes have used a variety of techniques to estimate damages arising from injuries to natural resources that stem from releases of hazardous substances (CERCLA) or oil (OPA). We selected two cases and prepared panel summaries for each to organize this discussion.

Panel 3 summarizes the hedonic components of one of the earliest NRDA cases to use property value methods. It concerned contamination of a stretch of the Eagle River with hazardous substances from the mine tailings of an abandoned silver mine, the Eagle Mine. Figure 1 provides a map of the affected area, which is not too far from the Vail Ski Area in the Colorado Mountains. The map is included to identify the location of the town with most home sales in relation to the mine site and the river. Metals and other contaminants from the mine and its tailings ponds were entering the Eagle River with alleged adverse effects. Energy and Resource Consultants, Inc. (with the research team led by Robert Rowe and William Schulze) conducted the economic analysis in support of the state’s case (Rowe and Schulze [1985]). They conducted two surveys, one in Eagle County where the mine was located and one statewide. Both contained contingent valuation questions about the damages. The local survey also obtained information on the residence of the respondent. The data included the location of the residence and its characteristics, the rent paid or the purchase price and date, and an estimate of its current value on the real estate market. These data were supplemented with an index of the
distance to the ski areas. The purchase price adjusted to 1985 dollars was used for the hedonic regressions. They were able to use data on 151 homes within a 25-mile radius of the mine.

Panel 3 summarizes a few key features of the hedonic models described in the plaintiff expert’s report. We report a few of the estimated coefficients from the linear specification. Proximity refers to a dummy variable indicating the property was within six miles of the site. Qualitative variables are given for structural characteristics of the homes. The ski access measure sums (with equal weight) ski acres at Vail relative to driving distance and a comparable measure for Beaver Creek (two well-recognized nearby ski areas).

The rationale for the analysis described in the expert report proposes the equivalent of a “cross check” role on the use for environmental amenities values for local residents that were likely to be impacted by the river’s contamination. The report suggests that using the hedonic to estimate willingness to pay would provide an overestimate.

A different use for the analysis arose after the defendant’s expert report became available. One component of the injuries due to the releases of hazardous substances involved documented contamination of at least one homeowner’s private well. The defense estimated the loss using what was suggested to be a perfect substitute – bottled water. In this context, if we interpret proximity to the site as a proxy for increased
likelihood of experiencing contamination of a home’s drinking water supply, we have a direct basis for comparing computed private mitigation costs with one measure of willingness to pay.

At the bottom of the panel we develop just this comparison using the defendant’s discount rate. This type of comparison is extremely effective in this setting. A “market” estimate of the loss was found to be over two and a half times larger than the computed mitigation cost, the only cost the defense was willing to acknowledge. This made the defense estimates seem implausibly low and thereby indirectly raising questions other components of the defense’s work.

The second natural resource damage case, described in Panel 4, involves a long-standing case involving New Bedford Harbor in Massachusetts. Polychlorinated biphenyls (PCBs) were released over a long period, but their presence was unknown until 1976, and seriousness of the problem was probably not widely appreciated until late 1979 when public health restrictions were announced. Debate about the risks continued throughout 1980-81. The pollution was greatest near the site of the release in the inner harbor. Pollution levels were high throughout the inner harbor, and the pollution migrated outside the barriers of the inner harbor although the levels were lower. Far enough out, the levels were undetectable. Three zones of restricted harbor use were defined by the Massachusetts Department of Public Health. Houses in zone I, identified in Figure 2, were associated with the Inner Harbor, where swimming, lobstering and all fishing were precluded. In zone II (also on the map in Figure 2), the restrictions on the neighboring waters were not as limiting. This area extends from the hurricane barrier to a point four miles out from the harbor. In this area lobstering and bottom fishing were
prohibited. The last restrictive area, the waters adjacent to zone III, had prohibitions only on lobster fishing. Zone IV on the map was associated with no PCB contamination and is free of restrictions.

The challenge posed in this case was to describe how the injuries to natural resources affected people. In the case of swimming, fishing and lobstering, the restrictions have direct impacts on the costs of undertaking these activities. Provided there are substitute facilities, these are clear connections between the restrictions and constraints. Because the injuries motivated the restrictions on private choice, we have a reasonably clear line of causation.

However, it is also reasonable to expect that the injuries affected others who lived in the area, regardless of their decisions to undertake specific water-based activities. The hedonic analysis was an attempt to capture these impacts. The issue that arises is the same one we discussed with respect to the hedonic analysis of the RCRA corrective action rule and the Eagle River case – how does one represent the effects of contamination.

The New Bedford case used a carefully structured hedonic analysis for three towns – Fairhaven (652 observations on repeated sales), Dartmouth (389), and New Bedford (189) with efforts to collect information on modifications to the structures and to
evaluate local site attributes that might affect sales prices. Sales within two miles of the harbor were collected.

This study used a variant of the repeat sales techniques discussed earlier. Properties that sold more than once were included in the data set, and since only changes in price were used, characteristics of the houses were not necessary. The expert developing the analysis, Robert Mendelsohn, did not use the techniques discussed above to simultaneously generate a local real estate price index and a measure of the environmental effect. Instead he sought to deflate the prices by the GNP non-farm deflator or a statewide real estate price index, and he controlled for mortgage interest changes over time. He also included variables representing different lengths of time between sales and changes in census variables. He considered both linear- and log-differences for the prices. His preferred specification had two dummy variables. One indicated that the pair of sales spanned 1980 (the time the information became available) and the closest water was the polluted inner harbor. The other indicated that the sales spanned 1980 and the closest water was the polluted part of the outer harbor. Both of the dummy variables had the expected negative signs and were significant at the ten-percent level or better. The coefficient on the outer harbor dummy was larger and more significant. Some variations in the census variables included did not seem to alter the results substantially. Using distance to the release site did not indicate as consistent an impact.

The issue considered in Panel 4, and central to this analysis for the litigation, was the process of detecting when the event was known. The examples involving studies of hazardous waste sites used in policy relied on the development of site history and the
maintained assumption that the injury was known by a pre-defined date. The New Bedford case investigated this issue by systematically studying the impact of sales that bracketed each potential date assumed for the event. The change in the pattern of signs displayed in the panel shows a change in the effects of the most severe PCB zones interacted with the dates for the repeated sales that corresponds to the 1979 announcement – quite striking support for the framework’s ability to isolate an effect.\(^{39}\)

While one might question the ability to use this estimate and approximate the loss by assuming it was experienced by all homes in the zone, the role of the model in documenting a loss to private homeowners was direct and convincing.

**VI. Hedonic Models for Other Environmental Effects**

There are a large number of other environmental issues that have generated hedonic studies. To some degree, past success has made analysts “bolder” in their willingness to search for more subtle effects. It has also re-focused attention on innovative mixes of time and indirect measures of environmental effects. To organize a diverse array of research we have separated them into groups by the nature of the problem studied. We have chosen to categorize them along two dimensions. The first has to do with whether the environmental effect is current or in the future. By this we mean, is the effect actually observed currently? For example, air pollution is currently observed in various locations and improvements in air quality can take place over a relatively short horizon. On the other hand, some effects may not be realized until far in the future. For example, with an environmental hazard such as radon the health effects may not be realized until far in the future. Nonetheless, this future realization may
influence decisions today and thus affect property values. Another example is global warming, where the effects would be in the distant future, yet land values today may reveal information about those future effects.

The second dimension on which we stratify the studies is whether the environmental effects are relatively certain or not, at least when averaged over relatively short time periods. For example, the noise levels at a house from a nearby highway are quite predictable and thus fairly certain. On the other hand, some environmental effects are very difficult to predict. For example, it is impossible to predict that an earthquake will strike at a particular location within a particular time period. However, seismologists can provide forecasts of the probability of an earthquake at a given location. The environmental effect is a probability rather a certain event, but that probability can affect property values.

The studies discussed here are categorized by both timing and uncertainty, although we have not discussed all four cells. The case of current and certain has largely been covered in our discussion of policy analyses involving hedonics. If an environmental effect will not take place until the distant future, we assume that there is also uncertainty involved. The newest area of work with a significant and growing number of studies involve current and uncertain issues. Far fewer hedonic studies have dealt with future environmental events.

**Current and Uncertain Environmental Effects**

This category involves environmental risks where the risk is immediate but there is a high level of uncertainty concerning the actual outcome. Two examples may clarify our classification of these studies. A landfill that accepts non-hazardous household waste
may have external effects such as heavy truck traffic and flocks of seagulls. These effects are quite predictable. They are current and certain and thus would fit in that group. On the other hand, there is usually a great deal of uncertainty about the effects that may result from a hazardous waste site. Residents may be aware that one exists, but there is uncertainty about the effects that may result. It may not be known where the waste has migrated off site. It may not be known what the effects on the surrounding population will be. There may even be questions about when and how the residents become aware of the risk and when and how they revise their risk perceptions in the face of new information. These issues are critical for estimating the willingness to pay for reductions in environmental risk.

The first major hedonic study to incorporate risk in a hedonic model was Brookshire, et al. [1985], which was an outgrowth of work funded by the U.S. Geological Survey. The researchers studied the effect of a 1972 California law that required that the purchasers of houses to be informed if the house was located in an area that was prone to earthquakes. They found that after the Act, houses located in those zones sold at a discount, although before the information was available (before the Act) there was no statistically significant discount. They used the estimate and their expected utility model to evaluate if there was evidence that people's self-insurance by location accorded with the implications of the expected utility framework. Their conclusion was that the hedonic results supported the model.

While this study of earthquake risk was done quite early, most of the subsequent developments on incorporating risk in a hedonic framework have come from research on hazardous waste sites. Some of the innovations discussed here are related specifically to
the uncertainty, while others have more general application. These innovations have not yet played a direct role in policy. Nonetheless, they have been influential and may well play a larger role in the future. We discussed studies of hazardous waste sites funded by the EPA during the early 1980's. Here we will focus on the innovations in methodology. Michaels and Smith [1990] used disaggregate housing data from the Boston area and eleven hazardous waste sites in their study. They analyzed whether the entire suburban Boston area could be considered a single market and used realtors to stratify their sample by the quality of the housing and area. This type of segmentation was an alternative to the previous debate on segmentation by location. They found that the effect of distance to the nearest hazardous waste site was of the expected sign and statistically significant after the waste site was known when the area was treated as a single market. When the submarkets were used, they obtained the expected signs (except in the below-average market), but they were not always statistically significant. They also examined whether the impact differed with the time from the announcement of the site, an issue that has been examined a great deal since then and, as we noted, was an important component of both the policy and litigation uses of hedonic models with this class of effects.\textsuperscript{41}

A study by Stock [1991] used the same data as Michaels and Smith [1990]\textsuperscript{42} but very different techniques. He developed nonparametric estimates of the benefits of clean up at two of the sites. The nonparametric methodology had not been used previously for environmental property value studies. He also developed risk measures that were based on the sum of the inverse of the distance squared to each of the sites and in one case weighted the inverses by the area of the sites. Considering multiple sites and considering
the characteristics of the sites was one of his contributions. Unfortunately, both the parametric and nonparametric techniques yielded imprecise estimates.

At about the same time, Kohlhase [1991] was considering the National Priority List hazardous waste sites in Houston. She used distance and distance squared to the nearest toxic waste site, but did not consider the characteristics of the sites or sites further away. Her study considers the effect of Superfund legislation on the perceptions of hazardous waste sites and, in turn, the perceptions' effect on property values. Three time periods were used: before the legislation was passed, after it was passed but before most the sites had been listed, and after all sites were listed. While the sites existed before the legislation, they did not have an effect on property values. Some of the hedonic results in the middle period were anomalous. However, after all sites were listed, the expected effect for distance was statistically significant.

Thayer, et al. [1992] did a comparison study of a non-hazardous waste site and a hazardous waste site. As expected, distance from the hazardous waste site was more valuable. They also found that the price gradient with distance for the sites seemed to level off.

Kiel and McClain [1995] considered a related environmental problem, the siting, construction, and operation of a hazardous waste incinerator. They used hedonic estimation in five time periods from before the site was rumored to after it had been operating a number of years. Their plausible results show that there is no effect on property values before the site is rumored or during the rumor stage. However, during construction and the beginning of operation, property values increase significantly with distance from the plant. After the plant was operating several years, the effect was
reduced in magnitude although it was still significant. Kiel [1995] conducted a similar timing study for a single hazardous waste site in the Boston area. Before there had been any news accounts, the site had no significant effect on property values, even though the site was operating. After that there was significant effect that remained even through the EPA's acceptance of clean-up plans.

Recently, there have been some new results on residents' learning about risk and its effect on property values. It is a common view that people's perception of the risk from hazardous wastes sites is significantly greater than expert's opinions of that same risk. Gayer, et al. [2000] use a Bayesian updating model for risk perceptions and hedonic regressions to address this question. The information comes from the release of EPA's Remedial Investigation. Once this information is available, they argue that the perceived health risk is substantially reduced. The hedonic results imply that the value of avoiding a statistical cancer case is reduced from about $50 million to about $4 million, which is in line with other estimates. This provides some evidence that the information in the Remedial Investigation is used by the residents to update their risk perceptions so the perceptions are more in line with objective risks. The study makes several improvements on previous studies. In addition to objective risk measures, they include NPL ranking of the nearest site, the time since the nearest site was placed on the NPL, the area and the type of operations there, and the number of non-NPL sites within different distances from the house.

In a related paper, Gayer [2000] considers the potential endogeneity of the hazardous waste site risk measures. We would expect that property values may be reduced by the risks associated with proximity to hazardous waste sites. On the other
hand, he suggests that when decisions are made about the location of a hazardous operation, surrounding property values are likely to be considered because of potential liability. Thus, he argues that the risk measure is likely to be endogenous. Using a Hausman [1978] test his estimates reject the null hypothesis of exogeneity. Moreover, there are fairly dramatic differences between the estimated effects of risk and the risk interactions with income (in the block group), education (proportion with college education in the block group), and the proportion nonwhite. While the empirical evidence is certainly supportive of his argument, the basic facts of the sources of the risk are not.

The risk measures included in the model are lifetime excess cancer risks estimated based on EPA risk assessments. These rely on soil and groundwater exposure models. While these estimates will be a function of the location of the site in relation to the households that could be exposed, the decisions about site location were made years before the decisions of current households to live in the area. It seems unlikely that firms could have anticipated these patterns or the processes that lead to the risks.

Thus, we find that the earlier Gayer, Hamilton, and Viscusi analysis is more convincing. It uses the logic of an event study to evaluate how information about sites, combined with the same technical risks, can be used to measure an individual’s incremental valuation of risk reductions.

**Distant-Future Environmental Effects**

Our final category of property value studies considers environmental events that are far in the future. Because of the time involved, one cannot observe the effect currently. There is also a great deal of uncertainty about the environmental events that
may take place, the physical effects that may result from the environmental effects, and
the human response to these events. However, it may be possible to infer something
about the various possible scenarios from data we can observe today. Such effects form
our third category. The main example we will consider is global warming and using
agricultural land values to estimate the economic effects.

This is not to suggest that the lines between this category and the previous one are
always clear. For example, the probability of experiencing an earthquake at a particular
location is quite low and may not occur until far in the future. Nonetheless, the
probabilities assigned by the experts are accepted by most individuals, and the risk,
however slight, seems immediate. For these reasons, we put earthquake risk in the
second category. With global warming, it is doubtful that the expected changes from
global warming are being capitalized in current land prices. However, we observe
varying climatic conditions today, and these conditions may affect land prices. The land
price differentials that are due to climate differences may provide insights into the effects
if climates change.

This insight is the basis of Mendelsohn, et al. [1994]'s analysis of the effect of
global warming on agriculture. They used the average farmland price per acre for each
county in the contiguous 48 states in the United States. They explained these prices using
data on the characteristics of the land, including 30-year average temperature and rainfall
in each of the four seasons. Because the data were county averages, they weighted by
cropland acres and by crop-revenue. Their predictions of the contribution of current
climate to current land prices did not differ much between the two weighting schemes.
However, when they applied a uniform doubling of CO$_2$ with a resultant 5° F increase in
temperature and an eight percent increase in precipitation across all land and seasons, the results differed by weighting. With the cropland weighting, land rents were reduced throughout the southern parts of the country. However, with the crop-revenue weighs, the warming was beneficial to much of the country and was only harmful in the mountain regions.

The Mendelsohn, et al. [1994] paper attempted a new approach to valuing the economic effects of global warming. Effectively, they are estimating a hedonic equation for agricultural land throughout the country. However, in their predictions of land values after global warming, they are assuming the price schedule will not change. A change in climate throughout the country (and world) is a major event that will have ramifications for the relative prices of the various crops. In turn, this would change the price of land with a particular vector of climate characteristics. Once the hedonic price schedule changes, the forecast of Ricardian rent changes is more complex. For example, if citrus crops could be grown throughout the southern half of the country, rather than just in California and Florida, the value of land where citrus crops could be grown would probably fall.

Subsequent authors (see Quiggin and Horowitz [1999] and Darwin [1999]) have raised questions with the specification and interpretation of this work. In their response to Darwin, Mendelsohn and Nordhaus [1999] highlight what they interpret as the “take away messages” of their paper

“... it was one of the first studies to demonstrate that cross sectional evidence could provide quantitative estimates of the economic effects of climate.”

“... it was one of the first empirical studies to demonstrate that warming could be beneficial”
“The MNS [Mendelsohn, Nordhaus and Shaw] study also revealed, however, that cross sectional analyses are demanding and can profit from constructive criticism” (Mendelsohn and Nordhaus [1999] p. 1053)

In this vein we believe this line of research on detecting long term signals in hedonic models is promising but just a beginning! It is especially important to consider the same range of issues raised with short term effects about what is being measured and how it relates to consumers’ willingness to pay or farmers’ profits.

VII. Implications and Next Steps

Hedonic models are one of the “success stories” of modern applied micro-economic analysis. They have gone from concept to practical tool in the evaluation of quality adjustments for new varieties of private commodities. Their role in environmental policy has been equally substantial but more indirect. Even in cases where the link between the policy (e.g., changes in specific air pollutants) and the measurement of attributes in a hedonic model is clear, their role in policy has remained indirect -- as a cross check to methods with links to policy that seem more tangible. This characterization is especially true for evaluating the health effects of air pollution policy. As our discussion of panel 1 suggested, the health risk orientation of U.S. air pollution regulations has required an evaluation of the health risks associated with different air quality standards. Rather than “disconnect” the benefit measures for these avoided health effects, most policy analysts have sought to monetize either the risk or the set of health effects associated with air pollution separately and to assume that they can be added. A hedonic model offers a composite measure because the air pollution measure enters the
model directly and the analyst does not attempt to evaluate the reasons for seeking improved air quality.

In other areas where the connection between the proxy used to reflect an attribute in the hedonic model and the objective of policy are not easily related, the results from hedonic models have not had a direct role. Their contribution is to offer suggestive evidence of a behavioral linkage. Even in situations where the connection between measures and policy outcomes is clear (e.g., water quality) and the regulatory mandate does not identify some effects as dominant (e.g., health effects with the criteria air pollutants), efforts to use hedonic findings in policy evaluation are largely confined to cases where they serve as checks. We believe the reason stems from concern that the hedonic models’ estimates may not fully reflect all the ways the resources influence people. Here we are not referring to nonuse values but rather to a diverse array of uses that may not be fully captured by the locational choices.

This concern is a commentary on the range of substitutes assumed available and the detail with which locational choice models are specified. Progress in integrating hedonics into these policies must await integrated models that address squarely the extent of overlap in benefit measurement methods, rather than offering simple statements that there are prospects for overlaps in estimates. This progress will only come through a willingness to develop specific structural models. Cameron’s [1992] joint estimation strategy that we discussed earlier is an example of what we have in mind.

Structural models must provide as part of the specification of the objective function and constraints a means to resolve the interrelationship between different estimates of the effects of disamenities. That is, when a behavioral model specifies
several different avenues for household adjustment, each is a potential source of a marginal willingness to pay estimate. In short, the model is spelling out how individuals can acquire substitutes for environmental amenities. If air quality around one’s residence is poor, does this imply the household takes more weekend trips to the mountains, is more likely to operate air conditioning before temperature and humidity conditions might imply it is needed, or simply avoids going outside on bad days? To the extent we can specify these adjustments and incorporate them consistently into a formal model of choice, it is then possible to establish a direct relationship between hedonic and other methods for non-market valuation.

Smith, Van Houtven, and Pattanayak [2002] have demonstrated that hedonic, travel cost, and contingent valuation estimates of water quality improvements can be combined consistently. This is the logic Cameron used to derive her joint estimator and could be applied to help resolve estimates derived from hedonic models with those for health risks. Indeed, Portney’s [1981] early computation of the value of a statistical life (VSL) from a hedonic property value model is an example of an application where a VSL estimate is derived from housing market evidence. It was based on the assumption that reducing the risk of premature death was the only reason for avoiding air pollution around one’s home.

Hedonic analyses have had more success in litigation. Property values change in response to an environmental problem because people are willing to pay to avoid the problem. Judges and juries are more convinced when people actually pay to avoid environmental disamenities or experience losses when they are discovered. The tangible evidence of an effect on people and their property has been convincing in litigation.
Hedonic work for litigation involves *ex post* estimation of damages at a specific location, whereas policy uses of hedonic results often involve *ex ante* application of results derived under different circumstances. The “hidden literature” we discussed raised some new issues worthy of further research. A few of the most promising include:

When do hedonic models actually provide a credible cross check? And are they upper or lower bounds? Can we do a better job at specifying what the relationship should be between the hedonic cross check and the other (effect-specific) estimates being used? We have presented results where they were interpreted both ways.

What is the influence of the socio-economic characteristics of neighborhoods or urban areas on the hedonic estimates obtained in those locations?

When an agency undertakes analysis of a significant environmental policy issue, is it really a “signal” in housing markets? This was clearly a concern of policymakers and would undermine our ability to publicly evaluate significant spatial amenities or disamenities. Will full disclosure of the decision process help mute these effects?

Can hedonic models help to identify environmental events through carefully designed repeat sales models or are selection effects too important a limitation?

What are the conditions for using hedonics to estimate values with very long-term events?

Economists maintain a fundamental confidence in a “law of one price.” That is, there are incentives that assure different people will pay the same price for the same commodity in well functioning markets. When we observe this is not happening it usually tells us something about restrictions on the markets, limitations in the information, or subtle differences in the commodities recognized by the people involved but not the analysts trying to describe their behavior. The hedonic framework is statistical detective work and has been very successful. Because many of its successes never make it into profession journals, we tried to combine some less known examples
with more recognized cases to gauge where we stand in valuing site specific environmental amenities. The record is remarkable, and the techniques have considerable promise for enhancing what we can learn about consumer preferences for spatially delineated externalities as housing sales price data become routinely available to researchers.
Figure 1 -- Location of the Eagle Mine and Eagle River
Figure 2 – Acushnet Estuary Study Area
Panel 1: Hedonic Property Studies as a “Cross Check”

<table>
<thead>
<tr>
<th>Benefit Category</th>
<th>Aggregation Procedure*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Mortality</td>
<td>1.12</td>
</tr>
<tr>
<td>Acute Morbidity</td>
<td>0.00</td>
</tr>
<tr>
<td>Chronic Morbidity</td>
<td>0.12</td>
</tr>
<tr>
<td>Household Sector</td>
<td>0.00</td>
</tr>
<tr>
<td>Soiling and Materials</td>
<td>1.24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Midpoint</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property Value Cross Check</td>
<td>3.43</td>
<td>6.85</td>
</tr>
</tbody>
</table>

* Present values in billions of 1980 dollars for 7-year period (1989-1995). Several “aggregation” procedures were considered. These refer to judgments about studies of the effects of air pollution that would be considered admissible. Six were done for this possible evaluation. The two reported here represent the most restrictive. (A) applies the CASAC standard from the health criteria document. Adjustments were made in (C) to allow for acute morbidity and soiling effects but to attempt to avoid double counting.

**Context:** EPA Analysis of Primary National Ambient Air Quality Standard for Particulate Matter

**Source:** Benefit Analysis Program

Office of Air Quality Programs and Standards

EPA (March 1983) conducted by Mathtech

**Task:** Measure present value of discounted benefits for ambient air quality standards for PM$_{10}$ and TSP; with implementation date of 1989; benefits are present value in 1980 dollars computed in year 1982 for time span covering 1987 to 1999 or 1989 to 1995; discount rate was 10% in real; all counties in compliance.
Panel 2: Hedonic Property Value Where Analysis Creates an “Event”

<table>
<thead>
<tr>
<th>Results From Hedonic Model for Facility I (1983-1991)*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simple Linear</strong></td>
</tr>
<tr>
<td>Period Indicator</td>
</tr>
<tr>
<td>(=1 after 1986.5)</td>
</tr>
<tr>
<td>(=0 before 1986.5)</td>
</tr>
<tr>
<td>Distance (miles)</td>
</tr>
<tr>
<td>From Facility x</td>
</tr>
<tr>
<td>Period Indicator</td>
</tr>
<tr>
<td>Distance (miles)</td>
</tr>
<tr>
<td>From Facility</td>
</tr>
<tr>
<td>Number of Rental</td>
</tr>
<tr>
<td>Homes</td>
</tr>
<tr>
<td>Distance x Rental</td>
</tr>
<tr>
<td>Homes</td>
</tr>
</tbody>
</table>

**Benefit Measures (Facility I, $1,000)**

<table>
<thead>
<tr>
<th>Move Each House 1 mile</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate</td>
<td>25,002</td>
<td>33,761</td>
</tr>
<tr>
<td>Per house</td>
<td>7.20</td>
<td>9.71</td>
</tr>
<tr>
<td>Move Each House 4 miles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregate</td>
<td>39,351</td>
<td>48,993</td>
</tr>
<tr>
<td>Per house</td>
<td>11.32</td>
<td>14.10</td>
</tr>
<tr>
<td>Event Reversal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Under Pre-Event Conditions</td>
<td>829,019</td>
<td>775,037</td>
</tr>
<tr>
<td>Under Post-Event Conditions</td>
<td>738,764</td>
<td>711,912</td>
</tr>
</tbody>
</table>

* Estimates were computed for 1992 by using time trend to adjust for price movements. Results from hedonic models are derived from a linear specification of the hedonic price equations with actual sales prices. The numbers in parentheses are the t-ratios for the null hypothesis of no association.

** Benefit measures are in 1,000 of 1992 dollars. Eighty percent of housing transitions were 2 to 4 miles from facility.

Context: Resource Conservation and Recovery Act (RCRA) Corrective Action Rule – cleanup of solid waste management units – at RCRA facilities; analysis applied
to a sample of 79 facilities – 70 non-federal and 9 federal facilities.

Source: Regulatory Analysis Branch
Office of Solid Waste
EPA (March 1993) conducted by Abt, ICF Industrial Economics Inc.
Hedonic analysis was led by Dr. R.G. Michaels

Task: Under the proposed rule EPA regions or states were expected to select corrective action remedies at RCRA Facility Investigation (RFI) and corrective measures study (CMS) reports submitted to the owners. EPA’s draft RIA projected that out of a universe of 5800 facilities, 2100 would conduct a CMS private implementation of corrective action. Of these, 2200 were projected to have released above the action levels to at least one environmental medium i.e., groundwater, surface water, air or soil. The analysis expected that groundwater remedies and soil cleanups would be most prevalent remediation activities.

The draft Regulatory Impact Analysis sought to measure benefits associated with human health risks, ecological threats, water use costs, ground water nonuse values, residential property values and hazardous waste facility values for the corrective action requirements.
Panel 3: Hedonic Property Value in Public Litigation – Challenging Lower Bounds

Summary of Hedonic Analysis

Sample includes 151 properties with a reported sales price; qualitative variable (0,1) indicating homes within six miles of Eagle mine site (proximity) measures the effect of the injury. It was argued that these households experienced “most dramatic perceived water quality effects.” Selected parameters from linear hedonic price function are given below, with t-statistics in parentheses.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Parameter Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity</td>
<td>-26,162.6 (-2.44)</td>
</tr>
<tr>
<td>Index of distance to ski areas</td>
<td>27,480.8 (6.29)</td>
</tr>
<tr>
<td>Condo</td>
<td>-30,514.5 (-2.30)</td>
</tr>
<tr>
<td>Townhouse</td>
<td>-29,886.4 (-2.18)</td>
</tr>
<tr>
<td>Duplex</td>
<td>11,682.7 (0.61)</td>
</tr>
<tr>
<td>Trailer</td>
<td>-54,445.1 (-3.91)</td>
</tr>
</tbody>
</table>

Summary of Mitigation Cost

Potable water needs for a household can be met with bottled water. These are estimated as $60 per month - $15 per month for the hot/cold water dispenser and $5 per bottle with nine bottles estimated per month. Annual cost estimated at $720 per year per household.
Per Household Comparison –
Annual Cost (1985 dollars)

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost (1985 dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hedonic Property Value*</td>
<td>$1,808</td>
</tr>
<tr>
<td>Mitigation Cost</td>
<td>$720</td>
</tr>
</tbody>
</table>

* This annual cost estimate uses the discount rate proposed by the defendant’s expert report 6.91%.

**Context:** State of Colorado Analysis of Natural Resource Damages due to contamination of stretch of Eagle River and groundwater with hazardous waste from mine tailings.

**Source:** Expert Reports for Case: Energy and Resource Consultants, Inc. conducted by Drs. Robert Rowe and William Schulze for plaintiff (State of Colorado) and NERA, Inc. conducted by Dr. Charles Cicchetti for defense (Gulf and Western Industries Inc.).

**Task:** Measure the losses to homeowners due to problems with drinking water and blowing dust from Eagle River Mine tailings ponds. Plaintiff used hedonic property value model with owners’ recall of sales price for properties within 25 miles of mine. Defense used cost of bottled water to replace well water for households that had contaminated wells.
**Panel 4: Repeat Sales – Injury as an Event**

<table>
<thead>
<tr>
<th>Year</th>
<th>Improve</th>
<th>Event</th>
<th>EVPCBZ1</th>
<th>EVPCBZ2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>1,092</td>
<td>-12,400</td>
<td>4,111</td>
<td>6,990</td>
</tr>
<tr>
<td></td>
<td>(6.63)</td>
<td>(-6.06)</td>
<td>(1.26)</td>
<td>(2.14)</td>
</tr>
<tr>
<td>1975</td>
<td>1,068</td>
<td>-15,150</td>
<td>5,482</td>
<td>11,640</td>
</tr>
<tr>
<td></td>
<td>(6.52)</td>
<td>(-7.45)</td>
<td>(1.86)</td>
<td>(4.05)</td>
</tr>
<tr>
<td>1976</td>
<td>1,079</td>
<td>-17,850</td>
<td>9,234</td>
<td>13,596</td>
</tr>
<tr>
<td></td>
<td>(6.86)</td>
<td>(-9.22)</td>
<td>(2.91)</td>
<td>(4.79)</td>
</tr>
<tr>
<td>1977</td>
<td>1,095</td>
<td>-13,870</td>
<td>9,290</td>
<td>10,160</td>
</tr>
<tr>
<td></td>
<td>(6.67)</td>
<td>(-7.59)</td>
<td>(2.98)</td>
<td>(3.62)</td>
</tr>
<tr>
<td>1978</td>
<td>1,071</td>
<td>-9,606</td>
<td>10,500</td>
<td>7,565</td>
</tr>
<tr>
<td></td>
<td>(6.41)</td>
<td>(-5.04)</td>
<td>(3.34)</td>
<td>(2.70)</td>
</tr>
<tr>
<td>1979</td>
<td>1,014</td>
<td>7,952</td>
<td>7,953</td>
<td>-1,729</td>
</tr>
<tr>
<td></td>
<td>(6.07)</td>
<td>(3.82)</td>
<td>(3.82)</td>
<td>(-0.64)</td>
</tr>
<tr>
<td>1980</td>
<td>1,076</td>
<td>16,920</td>
<td>-5,616</td>
<td>-6,338</td>
</tr>
<tr>
<td></td>
<td>(6.69)</td>
<td>(8.90)</td>
<td>(-1.94)</td>
<td>(-2.43)</td>
</tr>
<tr>
<td>1981</td>
<td>1,047</td>
<td>14,060</td>
<td>-8,609</td>
<td>-7,843</td>
</tr>
<tr>
<td></td>
<td>(6.45)</td>
<td>(8.05)</td>
<td>(-3.07)</td>
<td>(-2.96)</td>
</tr>
<tr>
<td>1982</td>
<td>996</td>
<td>15,800</td>
<td>-11,664</td>
<td>-8,160</td>
</tr>
<tr>
<td></td>
<td>(6.18)</td>
<td>(9.13)</td>
<td>(-4.09)</td>
<td>(-3.17)</td>
</tr>
<tr>
<td>1983</td>
<td>976</td>
<td>19,330</td>
<td>-13,660</td>
<td>-7,080</td>
</tr>
<tr>
<td></td>
<td>(6.13)</td>
<td>(9.56)</td>
<td>(-4.24)</td>
<td>(-2.40)</td>
</tr>
</tbody>
</table>

* The numbers in parentheses below the estimated parameters are the t-rates for the null hypothesis of no association. The models are distinguished by the timing of the event, as reflected by when it is assumed homeowners knew about the PCB contamination in the harbor. The variables presented are a subset of those in the model. Housing sale prices were deflated to constant dollars before computing the difference in prices between sales (1985 dollars). The independent variables in the model reported here are:
- **Improve** – value in thousands of 1985 dollars of improvements between the first and the second home sale based on building permit records.
- **Events** – qualitative variable (0.1) indicating the sale dates involved in the repeat sale bracket the date hypothesized for the event.
- **EVPCBZ1** – qualitative variable (0.1) that requires sales in the repeat sales bracket the date hypothesized as the event and property lies in the nearest PCB zone – that is,
property’s nearest rate lies in zone.
EVPCBZ2 – qualitative variable (0,1) that requires sales in the repeat sales bracket the date
hypothesized as the event and property lies in area of harbor with lowest traces of
PCB’s from hurricane barrier to four miles out (see Figure ).

**Context:** National Oceanic and Atmospheric Administration (NOAA), U.S. Department
of Justice and State of Massachusetts Analysis of Natural Resource Damages
due to PCB contamination of New Bedford Harbor.

**Source:** Expert Report for case by Dr. Robert Mendelsohn

**Task:** Measure losses to homeowners, due to injuries to resource from contamination
of harbor, with PCBs. Hedonic model assumes injuries due to PCB will be
reflected in residential property values for access once it is known that the
harbor is contaminated.
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As this paper was being prepared, Sherwin Rosen died prematurely of cancer. We would like to acknowledge his significant contribution to hedonic models and the profession in general through his research by dedicating this paper to his memory. Thanks are due to the series editors Henk Folmer and Tom Tietenberg as well as Shelby Gerking, Bengt Kristrom and an anonymous referee for most helpful comments on an earlier draft of this paper. Partial support for Smith’s research was provided by the U.S. Environmental Protection Agency under grant # R-826609-01.

1 The Bureau of Labor Statistics web site includes a number of working papers with hedonic price functions; see http://www.bls.gov/cpihome.htm.

2 Bartik and Smith [1987]; Palmquist [1991]; Freeman [1993]; and Palmquist [forthcoming] are examples of surveys that are oriented to the theory and methodology of property value studies.

3 Berndt [1991] credits Waugh with the first empirical hedonic study. For a discussion of the historical antecedents to the hedonic approach for dealing with quality attributes of goods, see Banzhaf [forthcoming].

4 As Banzhaf notes, Griliches initial proposal viewed the hedonic function as an empirical, rather than a theoretical, relationship. He offered two perspectives on the function. In one price was a function of the characteristics. The sample to estimate the relationship was varieties of the commodity. In the second, developed to account for changing attributes over time, he included dummy variables along with the characteristics to account for the base and subsequent years when new varieties were introduced.

5 The research is summarized in Ridker [1967].

6 It is interesting to note that the Public Health Service project also included another property value study. Hugh Nourse compared the trends in real estate price indexes near a metal fabricating plant emitting noxious odors and a nearby control area. (See Ridker [1967], Chapter 7 or Nourse [1967]) While the results were not entirely satisfactory, they foreshadowed the use of repeat sales to measure environmental effects, which will be discussed later.


8 In the case of air quality as measured by total suspended particulates, Smith and Huang [1993, 1995] found 37 empirical studies generating 86 estimates that were usable in their meta-analysis.

9 The scaling of an individual point estimate of marginal willingness to pay must address whether the change is large enough to induce a shift in the market equilibrium represented in the hedonic function. As noted by a variety of authors (i.e., Bartik [1988], Palmquist [1988] and Smith and Huang [1995]), such computations are also approximations at the individual level. A single hedonic price function does not, except with additional restrictive assumptions such as identical preferences across individuals, allow estimation of the marginal willingness to pay function.

10 Hedonic studies have been done for an extremely diverse set of differentiated products and factors of production. Environmental applications have almost always used real estate prices or wages. Hedonic wage studies involving spatially delineated measures of pollution have had little use in the policy arena. Wage hedonic models with information about job risks have been extremely influential to a wide range of areas in U.S. regulatory policy. The concept of the value of a statistical life, a measure of the incremental compensation required to accept the increased risks of a fatal accident, is the primary focus of these studies. See Viscusi [1993] for a review of this literature and Mrzek and Taylor [2002] for a meta-analysis of the available estimates. The emphasis in this chapter is on property value studies.
Graves, et al. [1998] do note concern with the magnitude of estimates of the marginal willingness to pay, noting that:

…estimates of the marginal valuations of nonmarket commodities, generated with the hedonic method, would change substantially with alternative estimating techniques… (O)ur findings cast doubt on the results of studies that have utilized the hedonic-based marginal prices to evaluate the validity of other nonmarket methods (pp. 220-221).

The debate began with Freeman [1971] and was soon joined by Anderson and Crocker [1972], Freeman [1974a], Polinsky and Shavell [1975] and Small [1975].

The work was first reported as part of a National Academy of Sciences/National Academy of Engineering report on *Air Quality and Automobile Emission Control* in 1974.

This measure is exact if there is free mobility within the urban area. If there are transactions and moving costs, bounds on willingness to pay are possible (Palmquist [1992b]).

Sieg, et al. [2001] use a locational equilibrium model to evaluate how the new computed equilibrium assignment of heterogeneous households and associated vector of housing prices (across communities) in response to an exogenous change in air pollution affects welfare measures.

In unpublished research Smith, Sieg, Banzhaf, and Walsh [2001] have shown that empirical measures of the Bartik upper and lower bounds for air pollutants in Southern California do not fall within a narrow band.

For an overview of the theoretical, econometric and empirical work on second stage models, see the hedonic surveys cited in footnote #2.

It is important to recognize the constraints on income elasticities that are imposed when we make assumptions that allow revealed preference methods, such as the hedonic model, to recover the marginal willingness to pay schedule. Smith [2001] has shown, for example, that the assumptions of weak complementarity and the Willig [1978] condition imply the income elasticity of the willingness to pay will equal the income elasticity of the private good that is the weak complement. Earlier it was also shown that it is possible to obtain some information about the effects of income on hedonic schedules without the second stage (see Palmquist [1992a] for this discussion and Smith, van Houtven, and Pattanayak [2002] for discussion of how they can be used in benefit transfer).

Cropper, et al. [1988, 1993] use an assignment model for simulations addressing estimation issues. Such models may prove useful in forecasting the *ex post* hedonic price schedule for use in benefit measurement. In a different type of model, Sieg, et al. [2000] forecast the price gradient after the equilibrium adjustment occurs.

Poulos and Smith [2001] apply propensity scores to evaluate whether it is possible to construct a spatial experiment with a repeat sales model that combines sales in an area experiencing impacts from a new interstate road with other areas that have not.

See, for example, Smith [1983].

The early work by Mathtech [1982], discussed below, did explore the feasibility of using wage hedonic models for plausibility checks, but none accounted for the jointness discussed in the Rosen-Roback framework.

EPA’s [1997] recent retrospective study of the benefits and costs from the Clean Air Act regulations from 1970 to 1990 bases the estimates of household soiling damages avoided on the Mathtech research (see Table J-2, Appendix I, pp. I-15 – I-19 for discussion).
There are no separate reports of the per household benefit measures, in part due to the complexity of the national policy evaluations.

The EPA also funded a series of projects on developing the hedonic method. McConnell [1984] headed a project devoted to the problems and prospects for estimating the second stage of the hedonic model. The most important work in that project was on the identification problem in the second stage. Certain aspects of this work were reported in McConnell and Phipps [1987] and Mendelsohn [1985]. Graves, et al. [1985], on the other hand, concentrated on the issues involved in estimating the first stage hedonic equation. They considered the specification of the hedonic equation, variable selection, measurement error, functional, and non-normal errors. A summary is contained in Graves, et al. [1988]. The EPA has continued to fund research on air pollution and property values today (Sieg, et al. [2001]).

In Brookshire, et al. [1982], discussed above in the air quality section, the contingent valuation survey used several techniques to present air quality including photographs showing visual range. However, the hedonic study used objective pollution measures for nitrogen dioxide and total suspended particulate matter. Later hedonic studies in the South Coast Air Basin (e.g., Murdoch and Thayer [1988]) did use visual range.

Smith was a reviewer for EPA for one of the versions of their efforts. A key argument in the proposal was the need for site investigations – visits by research staff of each area to determine whether the changes taking place could actually be attributed to water quality. In many respects, their logic was consistent with the search for natural experiments and instruments so common in literature on policy evaluation commonly used in labor economics and most recently proposed by Chay and Greenstone [2000] for hedonic applications involving air quality. To our knowledge, no one has suggested this connection to this early work.

With air pollution there may be little variation within a given neighborhood, but for many air pollutants there is variation throughout an urban area and air pollution is a consideration at all locations. With water pollution, once you get back a short distance from the water, the water pollution may have no relevance. However, see the next footnote.

This does not mean that there have not been interesting property value studies done in recent years. Two innovative recent studies have considered water quality. Leggett and Bockstael [2000] take advantage of a high irregular coastline in Maryland to obtain significant water quality variation within a single residential market for coastal properties. In several related studies (Lawson [1997]; Boyle, et al. [1999]; Michael, et al. [2000], differing water qualities on several lakes in Maine has provided spatial, in addition to temporal, variation. A second-stage hedonic model has been estimated (Boyle, et al. [1999]). If one broadens the category from water pollution to water-related effects, other interesting papers emerge. Lind [1967] modeled the relationship between flood control and land values, and his model had a significant effect on early property value work. Shoreline erosion is considered in Kriesel, et al. [1993]. Parsons [1992] use a repeat sale model to evaluate coastal land use restrictions. Smith and Palmquist [1994] consider temporal substitution, coastal rental property, and amenities.

They eliminated all variables that were not significant at the 10 percent level. They do not report their results with the full model.

This work was later published as Langley [1976].

This research provides early support for the logic underlying the locational equilibrium models recently proposed by Epple and Sieg [1999] for evaluating spatially delineated public goods.

For an overview of the early studies, see Nelson [1980].

Michaels’ thesis [1987] did investigate the implications of different distance based measures of the effect of hazardous waste sites in both hedonic models and in a linked random utility analysis.
Distance from a site is not the only way the hedonic equation could be estimated. Dichotomous variables for proximity to the site or different distances from the site can be used. Which specification is better depends on the way the site is perceived by nearby residents. Recent developments in spatial econometrics may broaden the range of choices here.

This conclusion is independent of the issues that would also be associated with the size of the impact in relation to the scale of the market and the plausibility of marginal approximations in these cases.

The McClelland, et al. [1990] study took a first step toward this process by using average risk perceptions of respondents in different areas around a landfill as attributes in their hedonic model.

Our access to documents from the two cases described here stem from the second author’s role in each case. In the first (the Eagle River Case), he was hired to “play” the plaintiff’s expert in a mock trial. As a condition of participation, he was given access to all documents from both sides of the case and allowed to write about the research. The second case (New Bedford Harbor), he was a member of a peer review panel providing plaintiff attorneys’ comments and guidance on the research activities undertaken as part of the litigation.

Mendelsohn, et al. [1992] repeat a portion of this analysis in their published paper. They altered the deflator used and several aspects of the specification so the numerical estimates are not comparable, but support the same general conclusion.

It is interesting to note that by 1971 there was a property value study of a solid waste disposal site (Havlicek, et al. [1971]).

Another study of hazardous waste sites (Smith and Desvousges [1986]) used the hedonic framework to motivate the research. Since the data came from a survey about willingness to pay for increases in the distance from a hazardous waste site rather than real estate data, we have not included it here, although it has been influential.

The data were developed by Harrison [1983] as part of an EPA project.

Gayer [2000] acknowledges that there is a wide disparity between siting decisions and the sales data he has available, but argues that the elements of a dynamic process reinforcing an initial site location can be uncovered from the more recent data. He does provide information on how this judgment can be supported, aside from the exogeneity test itself. Thus, in fairness, the issue requires further work within a more complete dynamic framework.

Schulze, et al. [1986] also used the framework of an event study to investigate how the amount of time after an announcement was made affected the sales price/distance relationship. Michaels and Smith [1990] found similar sensitivity, supporting the view that these asset markets can also signal the effects of information.