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Abstract

A house is a bundle of many goods: The number of bedrooms, bathrooms, the quality of local public services, the tidiness of a neighbor's yard, and the quality of the local environment. If transactions in the housing market reflect the interaction of informed buyers and sellers, then the price that the house sells for is the sum of the prices the buyer is willing to pay for each individual characteristic of the house. It is this notion that motivates environmental economists to study property values. If individuals consider the local environment as a component of the house they purchase, then information on the house and its sales price allows researchers to 'tease out' the price that individuals would be willing to pay for environmental goods. This approach relies on the use of the hedonic price model.

JEL Classification Codes: Q51, Q53, R2

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Chapter 6

Environmental Contamination and House Values

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6.1 Introduction

A house is a bundle of many goods: The number of bedrooms, bathrooms, the quality of local public services, the tidiness of a neighbor's yard, and the quality of the local environment. If transactions in the housing market reflect the interaction of informed buyers and sellers, then the price that the house sells for is the sum of the prices the buyer is willing to pay for each individual characteristic of the house. It is this notion that motivates environmental economists to study property values. If individuals consider the local environment as a component of the house they purchase, then information on the house and its sales price allows researchers to 'tease out' the price that individuals would be willing to pay for environmental goods. This approach relies on the use of the hedonic price model.

Economists are interested in hedonic studies involving environmental goods for several reasons. The first is that such studies reveal how much property values decline due to the environmental externality; this leads to an estimate of how much compensation would be required for individuals who experience the externality. This also provides a measure of (at least part of) the damages that individuals suffer from the externality (Kiel and Zabel 2001). The second reason to estimate the price of an environmental good is to be able to estimate the demand function for the good in question (Zabel and Kiel 2000). Knowing the demand curve allows economists to estimate the benefits from a reduction of the externality, as this is the relevant area under the demand curve.

This chapter considers the economic theories that lie behind this approach and will discuss the assumptions one must make in order to use the model to obtain price estimates of environmental goods. We will then study how one goes about estimating these dollar values, examining both the hedonic and repeat sales approach. We will consider data requirements, variable specification, and functional form. The use of the model in both time series and cross-sectional contexts will be examined. Finally, we will examine the empirical literature to better understand the current uses of the methodology.

6.2 Theory

In order to estimate how much individuals are willing to pay for a non-marketed good, such as an environmental good, there are two categories of approaches. Economists generally prefer to use what are called revealed preference models, where the actions of individuals are observed in the market, rather than reported in a survey situation—what is called a stated preference—although both approaches are used by environmental economists.

Hedonics is a revealed preference approach that uses property values to measure the price people are willing to pay for environmental goods, such as improved air quality or cleanup of nearby contaminated sites. The concept is based on the idea from Griliches (1971) and Rosen (1974) that many characteristics affecting quality of life are considered when buying a house, and that consumers' preferences regarding the characteristics will be represented in the price that they are willing to pay for the house. Such characteristics include the number of bedrooms, local school quality, air quality, and distance from contaminated properties. For example, a consumer may be willing to pay a higher price for a house that is located farther away from a contaminated site than for an otherwise identical house that is located next to a contaminated site. Hedonic regressions can be used to measure the consumer's willingness to pay for a house given changes in the distance from the contaminated site, holding all other characteristics of the house constant.

Following Rosen (1974) the model is based on individuals who maximize their utility, which is a function of many things, including the goods that they purchase (see Freeman (2003) for an excellent discussion). When they purchase a house, they consider the utility they obtain from the characteristics of the house and its location. The entire utility function is optimized given the prices of the goods, the individual's income, and any other relevant constraints (e.g. time). At the optimum, the marginal utility per dollar spent on each item (or each characteristic of the house) is equal across all goods (or characteristics). The individual's willingness to pay for the housing characteristics can be used to obtain their 'bid' function.

Suppliers of housing maximize their profits given their production function and the costs of inputs. The solution to their problem yields their 'offer' function. In the market buyers and sellers meet, and when houses are bought and sold, the resulting sales price comes from an intersection of the bid and offer functions. Thus the hedonic function depends on the interaction between the supply and demand sides of the market.

Underlying the hedonic model are several important assumptions. First, the prices observed must be the result of buyers maximizing utility and sellers maximizing profits so that the housing market is in equilibrium. Although it is highly unlikely that this assumption holds in the housing market, if the prices adjust relatively quickly the estimated coefficients should still reveal buyers' and sellers' preferences (Freeman 2003). Whether or not the presence of an environmental 'bad' slows down that adjustment process is an empirical question. The second assumption made is that all the characteristics of the house need to be known by the buyer so that the prices of the characteristics are summed into the sales price of the house. If the buyer is unaware of a characteristic then the price paid may not reflect the 'true' value of the house. In the case of some characteristics, such as the number of bedrooms, it is reasonable to believe that both the buyer and the seller have the same information. In the case of an environmental externality, it is possible that the buyer does not know of the existence of the externality so the coefficient estimated may be incorrect. Again, the extent of the buyer's information is an empirical question. The third assumption is there cannot be any discrimination in the housing market; if there is, then the characteristics of the buyer, not just of the house itself, affect the sales price of the house. Since there is evidence of discrimination in housing markets, (e.g. Kiel and Zabel 1996) it is likely that this assumption fails. In addition, the inability of any group to purchase a house for other than economic reasons divides the housing market into separate groups, which violates the next assumption. The fourth assumption is that the housing market being examined must be a single market, not a segmented market. This is because the equilibrium condition requires a single market if only a single equation is being estimated (Taylor 2003). Researchers can test for market segmentation econometrically (see Taylor and Smith 2000 for an example). Clearly these four assumptions are all interrelated and if these assumptions are not correct, then the observed price of the house may not fully reflect the house's characteristics.

A typical hedonic regression equation is:

$$P_i = \beta_0 + \beta_1 H_i + \beta_2 N_i + \beta_3 ENV_i + \varepsilon_i, \tag{6.1}$$

where P_i is the sales price of the ith house, H_i contains information on the characteristics of the house (such as number of bedrooms), N_i contains information on the neighborhood in which the house is located (such as quality of the local school), ENV_i contains information on the local environment, and ε_i is the unobservable stochastic random error. The βs, thus, are the marginal impact of a unit change in the characteristics on the price of the house; specifically, they are the marginal prices of the included characteristics that are determined in the housing market.

The researcher needs to obtain data on the price of the house, as well as all the relevant characteristics that affect the price. These data can be used to estimate the equation above using ordinary least squares (OLS). Once the coefficients have been estimated, the researcher can then use them to calculate the marginal prices of the characteristics. How that is done depends on the functional form of the hedonic regression. If it is a linear form as in equation (6.1), the marginal price of that good is:

$$\partial P_i / \partial ENV_i = \beta_3. \tag{6.2}$$

Thus the marginal price is simply the estimated coefficient. If the hedonic regression is in semi-log form:

$$\ln(P_i) = \beta_0 + \beta_1 H_i + \beta_2 N_i + \beta_3 ENV_i + \varepsilon_i, \tag{6.3}$$

then:

$$\partial P_i / \partial ENV_i = \beta_3(P), \tag{6.4}$$

where the estimated coefficient is multiplied by the dependent variable. Researchers generally use the average of the dependent variable to calculate the price of the environmental good. If the regression is in log-linear form:

$$\ln(P_i) = \beta_0 + \beta_1 \ln(H_i) + \beta_2 \ln(N_i) + \beta_3 \ln(ENV_i) + \varepsilon_i, \tag{6.5}$$

then the price is:

$$\partial P_i / \partial ENV_i = \beta_3(P_i / ENV_i), \tag{6.6}$$

where the coefficient is multiplied by the ratio of the dependent variable to the environmental variable. Researchers generally use the averages of those two variables to calculate the price of the environmental good.

The functional form of the hedonic regression is an important consideration. If a linear function is used, then this implies that consumers can unbundle the house's characteristics costlessly (Rosen 1974). In the more likely case that characteristics cannot be easily exchanged, a non-linear functional form is called for; in this case the estimated price of the characteristic depends on the quantities of the other characteristics that are consumed. A paper by Cropper et al. (1988) tests various functional forms and finds that the linear Box-Cox transformation is most appropriate.

Clearly, many of the characteristics of the houses are likely to be statistically correlated. It is reasonable to expect that larger sized homes have more rooms, and that older houses are more likely to be in more densely populated areas. One way to minimize the correlations between included variables is to model the changes in the characteristics rather than the levels. Within the hedonic framework, this approach is called the 'repeat sales' technique. The underlying assumption is that the hedonic model does not change over time. Thus, if a house sells twice, then the difference between the two hedonic equations yields an equation where only those characteristics that change over time are included, as the other characteristics drop out. This adds to the benefits of this approach: The researcher needs data only on those characteristics that do change, and unobserved characteristics that don't change over time drop out as well. In a standard hedonic model those unobserved characteristics would bias the estimated coefficients, but that is not an issue in the repeat sales model.

The earliest repeat sales model comes from Bailey et al. (1963) in their effort to create a house price index. The regression they estimate is:

$$\ln(P_{it} / P_{it-1}) = -\ln(B_{t-1}) + \ln(B_t) + \ln(U_{it,t-1}) \tag{6.7}$$

where P is the price of house i at sale time t (last sale) or t-1 (first sale), B is a "true but unknown index" of real estate prices (Bailey et al., page 934), and the error terms (U_i) are uncorrelated with each other. The independent variables included in their regression are simply dummy variables that equal –1 at the time of the first sale, +1 at the time of the second sale, and zero otherwise.

Case and Shiller (1987) extend Bailey et al.'s (1963) model by allowing the variance of the error term to vary across houses. They do this through a series of three regressions. First, they run the Bailey et al. regression. They next use the squared residuals from that regression as the dependent variable in a second regression where the independent variables are the time between the two sales and a constant term. Their final regression is a generalized least squares (GLS) regression where each observation is corrected by dividing by the square root of the fitted value from the second regression.

Thus, there are several ways to develop a repeat sales model. Which approach is chosen will depend on the data available, as well as how the researcher chooses to model the process being observed.

6.3 Data Requirements for the Hedonic Regression

The equation to be estimated is:

$$P_i = \beta_0 + \beta_1 H_i + \beta_2 N_i + \beta_3 ENV_i + \varepsilon_i, \tag{6.8}$$

where P_i is the sales price of the ith house, H_i contains information on the characteristics of the house (such as number of bedrooms), N_i contains information on the neighborhood in which the house is located (such as quality of the local school), ENV_i is a measure of the environmental variable of interest, and ε_i is the unobservable stochastic random error. The regression can be estimated using cross-sectional data or a panel data set, depending on the model being used by the researcher and the data available. Both will be discussed later in this paper.

The dependent variable is the value of the house. The most commonly used measure is a recent sales price, as this is reached by an agreement between a buyer and a seller, and, usually, it is measured without error when the deed is registered. Other studies (e.g. Steinnes (1992)) have used assessor's data although one must be careful about how recently the assessment was performed. Census data (including the American Housing Survey) can also be used (e.g. Harrison and Rubinfeld (1978)) but the house's value is given by the owner in answer to the question "what price would the house sell for if it were on the market today." There can be errors in the values given, but Kiel and Zabel (1999) have shown that, although the average owner overvalues their house by 5%, the errors are generally random and should not affect the estimation process. An advantage of these data is that the characteristics of the house are given by the owner, and thus are likely to be current.

The independent variables are meant to capture all the relevant characteristics of the house and its neighborhood that will impact on the value. Thus, deciding which to include will depend on the data available and on the tradeoff between parsimony and completeness.

In the case of transaction data, the characteristics of the house can be those included in the realtor's listing, or those included in the local assessor's database. The researcher must be careful that the characteristics are those from the time of the sale; this is more likely with realtor's data than with assessor's data. If the latter are employed then it is helpful to identify recent changes to the property by examining data on permits filed by the owners. If a cross-sectional model is being used, then it is important to include as many characteristics as possible. If a repeat-sales model is being estimated, those characteristics that do not change over time can be excluded. However, identifying those characteristics that have changed between the two sales dates is crucial if the estimates obtained are to be accurate.

Similar issues arise in choosing the neighborhood variables to be included. As realtors like to say, the three things that affect the price of a house are 'location, location, and location.' Thus, it is crucial that the relevant characteristics be included in the estimated regression. Typical measures include: Local school quality, local crime rates, distance to the nearest highway, etc. If the researcher is examining houses in a single town, then town-level variables can be ignored. However, if several towns are included in the data set, then variables such as local tax rates must be included. But how 'local' are the impacts? The question of 'what is a neighborhood' must be considered.

In a paper by Kiel and Zabel (2004) this was explored using a unique data set based on the American Housing Survey. The authors estimate similar regressions on house values including variables measuring neighborhood quality at the very local level (the ten nearest houses to the house being studied), the town level, and the metropolitan area. They find that all three measures of 'neighborhood' are important in the regressions, thus it appears that individuals value quality at both the very local and the larger surrounding area. It is often difficult to obtain data at the street level, but Kiel and Zabel report that the estimated coefficients from regressions that do not include such data are not statistically different from those estimated in regressions where such data are incorporated.

6.4 Inclusion of Environmental Variables in a Hedonic Regression

The independent variables of greatest interest for our purposes are those that measure the local environment. It is important that the variable measures the environmental aspect in a way that best represents how the buyer thinks about the (dis)amenity. In some cases this can be quite straightforward. For example, when considering a toxic waste dump, it seems most likely that individuals consider how far the house is from the site. Thus, a simple measure of distance is a reasonable way to capture the amenity. However, with other types of pollution, it can be more complicated. Air quality is one such example: How do individuals think about air quality? Are they concerned with parts per million of certain types of pollutants (e.g. nitrous oxides) or are they more concerned with overall totals of all criteria pollutants? Are they focused on health impacts or on visibility? Do they care only if the pollutants exceed some threshold, or do they care about the actual level of the pollutant?

Many hedonic studies have been done on air quality—see Smith and Huang (1995) for a meta-analysis, and Boyle and Kiel (2001) for a review of studies; their table presented here as Table 6.1–and the results suggest that it does impact house prices. Smith and Huang (1995) report that the thirty-seven studies they reviewed attempted only to establish the existence of a link between the two, and did not focus on obtaining the most accurate prices people were willing to pay. Boyle and Kiel report that the studies they reviewed were too different to determine if the prices found by other researchers were 'similar' in any sense. Because researchers use different measures of air quality (different pollutants as well as different units of measurement), the results cannot be compared for consistency.

Hedonic studies that look at the impact of undesirable land uses on property values are reviewed in Farber (1998) and Boyle and Kiel (2001). Farber looks at twenty-five studies[i] where the impact is generally measured as 'distance from the site' and reports that there is "considerable agreement" (Farber 1998, page 11) on the price effects, which range from $3,000 to $15,000 per mile in 1993 dollars. The landfills and coal-fired electric utility had an impact of $14,000 per mile, which he notes is surprising, but since there are only a few studies on these types of facilities, he does not feel the discrepancy is too troubling. Chemical plants and nuclear power plants decreased property values by $200 to $300 per mile. Boyle and Kiel (2001)—summarized here in Table 6.2–examine sixteen studies of locally undesirable land uses and find that the increases in house prices from increasing the distance from the site by one mile ranges from $189.77 to $11,452 in 1982-84 dollars. They point out that this variation is large, and that the price effects are impacted by changes in information about the site. Thus, it is important for studies to control both for distance from the site and changes in information available to the public.

Kiel and Williams (2003) conduct a meta-analysis of house price regressions where the environmental variable of interest is the distance from the nearest Superfund site. Their data set consists of single-family house sales prices in thirteen U.S. counties where there are a total of fifty-seven Superfund sites. Hedonic regressions were estimated for different time periods based on when the site was discovered, when it was listed and so on. For the regressions based on the period just after the site was listed by the EPA, they find that eighteen sites were viewed as negative externalities such that as distance from the site increased, house values also increased. There is substantial variation in the impact: In percentage terms it ranges from 0.94% to 92.06% with a mean of 16.26% and a median between 6.34% and 7.52%. Seven other sites were found to increase local house prices, while the regressions on the remaining sites did not yield statistically significant results.

Kiel and Williams (2003) then look at the sites to see what might cause the differences in house price responses. They run a regression where the dependent variable takes on a value of 1 if the original hedonic regression found that the site was viewed as a negative externality, and a value of zero otherwise. They find that larger sites are more likely to be viewed as negative externalities, while sites in counties with a higher percentage of blue-collar workers are less likely to be viewed as negative externalities.

Water pollution studies are summarized in Boyle and Kiel (2001); their table presented here as Table 6.3. They examine seven studies and report that water pollution, whether measured as pH readings, secchi disk readings, coliform concentrations, or ratings by local officials, decreases property values. Boyle and Kiel suggest that the studies that use measures that are most easily observed by people, such as water clarity, have the 'best' results.

Just as it is important to include all relevant housing and neighborhood characteristics, it is important to include all relevant environmental characteristics in the estimated equation. However, very few studies have done so; most focus on one particular environmental characteristic to the exclusion of all others.

Boyle and Kiel (2001) examine three studies that use multiple measures; Blomquist et al. (1988), Thayer et al. (1992), and Clark and Nieves (1994). The results from these three studies are generally as expected although some results are surprising. For example, Blomquist et al. (1988) find that only one measure of air quality and of water pollution are of the expected sign; the other environmental measures are of the wrong sign and most are statistically significant. Of course, this could be due to multicollinearity between the measures, although the authors do not report correlation statistics.

Table 6.1 Air Quality Studies

	Year	*Dependent Variable:*	*Independent Pollution Variable:*	*Sign of Pollution Variable, Statistical Significance:*	*$ Value of Pollution Estimate (reported):*	*$ Value of Pollution Estimate (real, base period: 1982-84):*
Ridker and Henning	1967	Median Property Values by Census Tract (1960)	Index of sulfation Levels	Negative, ss at 5% level (t=2.03)	Drop by 0.25 mg/100cm2/day increases value by $83 - $245	Drop by .25 mg/100cm2/day increases value by $280 - $827.70
Wieand	1973	Monthly rent per acre of land (1960)	Suspended particulates, sulfur dioxide, and sulfur trioxide	Negative, not ss negative, not ss positive, not ss	___________	___________
Deyak and Smith	1974	Median property values by SMSA (1970)	Geometric mean of suspended particulates lagged one year	Negative and ss at the 10% level or better	Not reported	___________
Smith and Deyak	1975	Median property value, median rent in SMSA (1970)	Level of suspended particulates	Negative, not ss	___________	___________
Harrison and Rubinfeld	1978	Median house value by census tracts (1970)	Concentration of nitrogen oxides squared	Negative, ss at the 99% level	Average annual benefits per household range from $59.17 to $118.00	Average annual benefits per household range from $152.50 to $304.12
Nelson	1978	Median property value by census tracts (1970)	Particulate concentration, summer oxident concentration	Negative, all particulate coefficients ss at the 95% level, only one oxident coefficient ss at the 95% level	$57.61 per microgram/m3, $14.11 per 0.001 ppm	$148.48 per microgram/m3;$36.37 per 0.001 ppm
Li and Brown	1980	Sales prices (1971)	Mean values of TSP and sulfur dioxides by census tracts	Negative (except one Sulfur dioxide coefficient), none are ss	___________	___________
Palmquist	1982	Sales prices (1977)	Second high readings for TSP and ozone, arithmetic means for nitrogen dioxide, median for sulfur dioxide from nearest monitor and	Negative half the time for TSP, ss in 6 of 20. 8 of 18 nitrogen dioxide negative and ss. 8 of 12 ozone negative, 6 ss. 5 of 20 negative and	TSP: -$8.85 to -$59.78 per µg/cu3NO2 : -$8.12 to -$178.21 per µg/cu3O3: -$42,929.40 to -$290,691 per ppm SO2: -$23.39 to -$132.37 per µg/cu3	TSP: -$14.60 to -$98.65 per µg/cu3NO2 : -$13.40 to -$294.08 per µg/cu3O3: -$70,840.59 to -$479,688.12 per ppm SO2: -$38.60 to -$218.43 per µg/cu3

			from weighted average of three nearest monitors	ss for sulfur dioxide.		
Palmquist	1983	Sales prices(1977)	Same	4 of 14 TSP were negative and ss. 7 of 13 nitrogen dioxide negative and ss. 4 of 12 negative and ss for ozone. 5 of 14 negative and ss for sulfur dioxide.	TSP: -\$8.46 to -\$54.09 per µg/cu3NO2 : -\$5.87 to -\$102.70 per µg/cu3O3: -\$24,602.80 to -\$288,159 per ppm SO2: -\$26.57 to -\$132.81 per µg/cu3	TSP: -\$13.96 to -\$89.26 per µg/cu3NO2 : -\$9.67 to -\$169.47 per µg/cu3O3: -\$40,598.68 to -\$475,509.90 per ppm SO2: -\$43.84 to -\$219.16 per µg/cu3
Murdoch and Thayer	1988	Sales price (1979)	Four indicator variables on probability of certain levels of visibility	All negative and ss at the 90% level or better	\$473 to \$7346 for a change in probability of 0.01	\$651.52 to \$10118.46 for a change in probability of .01
Graves et al.	1988	Sales price (1979)	Total suspended particulates and visibility index	TSP always negative and ss at 95% level, sign and significance of visibility varies	Mean of predicted price: visibility: \$6680TSP: -\$1180(based on specification 1, Table 6)	Visibility: \$9201.10TSP: -\$1625.34
Zabel and Kiel	2000	Owner reported values	Arithmetic mean of nitrogen dioxide readings and sulfur dioxide readings, and the second daily maximum hourly readings for ozone and total suspended particulates	23 of 80 estimated coefficients are ss at 95% level, 19 of those are negative	Not reported	______________

Note: Adapted from Boyle and Kiel (2001) reprinted with the permission of the American Real Estate Society.

Table 6.2 Undesirable Land Use Studies:

	Year:	Dependent Variable:	Independent Pollution Variable:	Sign of Pollution Variable, Statistical Significance:	$ Value of Pollution Estimate (reported):	$ Value of Pollution Estimate (real, base period: 1982-84):
Blomquist	1974	Average owners' stated value in census block	Effective distance from power plant	Positive and ss at 99% level.	Value increases by 0.9% for increase in distance of 10%.	————
Nelson	1981	Sales price (1977-79)	Dummy variable for before or after TMI accident, Dummy variable interacted with date of sale	Positive, not ss. Interaction is negative, not ss.	————	————
Gamble and Downing	1982	Sales price (1975-77)	(1) Dummy variable for whether the reactor is visible from the house; (2) distance from the house to plant	Neither variable ss	————	————
McClelland et al.	1990	Sales price (1983 - 85)	Neighborhood 'risk' measure	Negative and ss at 95% level	Closing landfill would increase values by $5001	Closing landfill would increase values by $4822.57
Michaels and Smith	1990	Sales price (1977-81)	Distance to nearest hazardous site, Distance interacted with variables for time of sale	All positive, interaction terms are ss	Benefits per mile for full sample: $115 (1977$)	Benefits per mile for full sample: $189.77
Kohlhase	1991	Sales price (1976-85)	Distance to toxic site, distance squared	Prior to Superfund status, coefficients not ss. After status, positive and ss, most at 95% level	Increase distance by one mile increases value by $2,364 (1985 $)	Increase distance by one mile increases value by $2,197
Ketkar	1992	Median owner estimated value (1980)	Number of hazardous waste sites in the town	Negative and ss at the 95% level for three of four model specifications	Cleanup of one site increases median property value by $1,300 to $2,000 (1980 $)	Cleanup of one site increases median property value by $1577.67 to $2427.18
Nelson et al.	1992	Sales price (1979-89)	Distance from landfill	Positive and ss at 99% level	Increase of distance of one mile increases value by nearly $5,000	Increase of distance of one mile increases value by nearly $4,554
Reichert et al.	1992	Sales price (1985-89)	(1) Distance from landfill; (2) distance and dummy for sales occurring at least one year after landfill opening; (3) dummy for combined impact of landfill and railroad	(1) Negative, not ss; (2) distance negative, not ss, dummy negative and ss; (3) negative, ss	Opening of landfill caused average depreciation in house values of $2,924 or 6.1% houses impacted by landfill worth average of $6,065 or 5.5% less than those not impacted	Opening of landfill caused average depreciation in house values of $2,574; houses impacted by landfill worth average of $5,339

Smolen et al.	1992	Sales price (1986-90)	(1) Distance to existing hazardous site; (2) distance to proposed hazardous site	(1) Positive and ss for houses within 2.6 miles of site; (2) positive but ss only for 1989 sales of houses 2.6-5.75 mi. from site	For houses within 2.6 mi. of the site each additional mi. from the site is worth between $9,300 and $14,200	For houses within 2.6 mi. of the site each additional mi. from the site is worth between $8,187 and $11,452
Flower and Ragas	1994	House sales prices (1979-91) (Values adjusted by authors based on a hedonic index)	(1) Dummy variables for proximity to one of two refineries; (2) distance to nearest refinery	(1) Only a few are ss at 95% level or better; (2) evidence of prices falling with distance (some are ss)	Range from $5,000 to $6,000 increase as distance increases 0.5 miles; one mile increase in distance increases value by $357 to $986	___________
Kiel and McClain	1995	Sales prices (1974-1992)	Distance from incinerator	Coefficient is not ss until construction phase, then positive and ss at 90% or better	Increase in distance of one mile increases values by $2,283 to $8,100	Increase in distance of one mile increases values by $2,336 to $7,214
Kiel	1995	Sales prices (1975-92)	Distance from nearest Superfund site	Coefficient not ss until discovery phase, then positive and ss at the 95% level in all periods except one	One mile increase in distance increases value by $1,377 to $6,468 (nominal)	One mile increase in distance increases value by $1,377 to $4,610
Carroll et al.	1996	Property price (1986-90)	(1) Distance and Distance squared; (2) dummy variables for distances from site	(1) Distance is positive and ss, distance squared is negative and ss for 3 of four sub-samples; (2) Dummy variable for houses within 2.5 miles of the site is negative and ss for all regressions estimated	For combined subsample, value increases at 4.56% at two miles away, explosion decreased values by 17.6%, relocation increased values by 38%; properties within 2.5 miles of the plant have 6.3% lower values	___________
Simons	1999	Sales prices (1996)	Dummy variable for being on the pipeline corridor, dummy variable for sales on the pipeline corridor after rupture	On corridor, positive and ss at 99% level, sale after the rupture negative and ss at 90% level	5.5% reduction in sales price on the pipeline corridor, average sales price is $285,000	Average sales price is $181,644.36

Note: Boyle and Kiel, (2001); reprinted with the permission of the American Real Estate Society.

Table 6.3 Water Quality Studies

	Year:	Dependent Variable:	Independent Pollution Variable:	Sign of Pollution Variable, Statistical Significance:	$ Value of Pollution Estimate (reported):	$ Value of Pollution Estimate (real, base period: 1982-84):
David	1968	Weighted sum of land values around lakes(1952, 1957, 1962)	Dummy variables for water quality based on opinions of government officials	Coefficients on moderate and good quality are positive and most are ss.	Not reported	___________
Epp and Al-Ani	1979	Sales price (1972)	(1) pH, entered linearly or in dummy variables, (2) perceptions of owners entered as dummy variable	Positive and ss at 99% level	One point increase in pH increases mean sales value by $653.96	One point increase in pH increases mean sales value by $1564.50
Young	1984	Sales price (1981 basis)	(1) Dummy variable for location on bay (2) rating of water quality by local officials	(1) Negative and ss at 95% level (2) Positive and ss at 95% level	(1) Polluted bay locations are worth $4700 less (2) polluted bay locations are worth $4200 less	(1) polluted bay locations are worth $5171 less (2) polluted bay locations are worth $4620 less
Steinnes	1992	Appraisal data (year not specified)	Secchi disk readings	Positive and ss at 99% level	1 foot improvement in clarity increases value by $206 - $240 per lot	___________
Mendelsohn et al	1992	Change in real house pricing(1969-1988)	Dummy variables for sales after pollution event, interaction between event and dummies for homes whose closest waters are polluted	Interaction terms are negative and ss under some specifications	Affected properties are $7000 to $10,000 lower in value (1989 $)	Affected properties are $5645 to $8,065 lower in value
Michael et al.	1996	Sales price per foot frontage (1990-1994)	Secchi disk readings	Positive and ss at the 95% level or better	1 meter improvement in clarity increases sales prices by $11 to 200 per foot frontage	1 meter improvement in clarity increases sales prices by $7.86 to $142.88 per foot frontage
Leggett and Bockstael	2000	House sales price (1993-1997)	Median coliform concentration, Distance from	Coliform coefficient is negative and ss at 90%	Change of 100 count per 100 mL leads to 1.5%	______________

	pollution source	level or better, distance is not ss.	change in prices

Note: Boyle and Kiel (2001); reprinted with the permission of the American Real Estate Society.

In a series of unpublished papers, Bowen and Kiel (2000) and Kiel and Bowen (2000, 2002) examine the impact of not including all relevant environmental variables in hedonic regressions. As they discuss, if a relevant variable is excluded from the regression, the model is misspecified. Econometric theory states that omitting relevant variables biases the estimated coefficients of the included variables, if the omitted and included variables are correlated with each other. It is quite likely—and some evidence is provided in the environmental equity literature—that environmental variables are correlated with one another. Thus, estimating an equation with only one of the relevant environmental variables will lead to biased estimates of the prices of the included variable.

For these studies, Kiel and Bowen use a unique data set that includes information on house sales prices and house characteristics from twenty counties in the U.S. to which has been added data on the census block group the house is located in, as well as several measures of environmental quality. Air quality is measured in several ways, as is information on the nearest Superfund site and hazardous waste site. They estimate hedonic regressions for St. Louis County in 1990 (2000) where they have purposely chosen environmental measures that are not correlated with each other. They find that estimating the regression using the environmental variables separately, as is common in the literature, gives the expected results in the case of the Superfund site, but that lower air quality leads to higher house prices. When the variables are added sequentially, they report that the estimated coefficients on the house and neighborhood variables are as expected and are generally stable, but that the environmental coefficients change both in sign and in statistical significance.

In another paper, Bowen and Kiel (2000) use the same data set to estimate repeat sales regressions for St. Louis County for sales that took place between 1979 and 1994. They hypothesize that by examining changes in variables rather than levels of variables, possible multicollinearity issues will be minimized. When using the differences in the sales prices as the dependent variable they obtain the expected results. However, when the dependent variable is the log of the ratio of the prices, the results are counterintuitive. The authors argue that the interactions among multiple environmental indicators may be too complicated to be captured by a simple hedonic regression.

The researchers' third paper (Kiel and Bowen 2002) examines house sales from seventeen U.S. counties in 1990. First, they estimate hedonic regressions with each environmental indicator included individually. The estimated coefficients are generally of the correct sign for distance from a Superfund site, a hazardous waste site, and a toxic release site. The air quality coefficients are of the expected sign but are statistically significant in only half of the estimated regressions. When the regressions are estimated with all the environmental indicators included, the results become unstable. Again, the authors argue that the relationship between the environment and local house prices may be too complicated to be modeled in this way.

The work by Bowen and Kiel confirms the results found by Smith and Huang (1993) in their meta-analysis. In an examination of over 50 studies of air quality and house prices, Smith and Huang report that adding more air pollution variables to the regression lowers the probability of obtaining a statistically significant coefficient on the variables. The authors suggest that this may be due to multicollinearity between the air quality variables.

As with other characteristics, whether the study is cross-sectional or time-series in nature will also influence the types of environmental characteristics that should be included. If panel data are used in a repeat sales model, then those environmental variables that do not change over the sample period will drop out of the regression; however, it is crucial that those variables that do change are included in the regression.

6.5 Empirical Applications

The earliest study using hedonic models to estimate the prices of environmental goods was by Ridker and Henning (1967). That study used Census data to examine the impact of air pollution on the median house value in census tracts. With the advent of more easily obtainable sales data, the number of studies has increased. There are several reviews of these studies (see e.g. Farber 1998; Boyle and Kiel 2001). We turn now to a few such studies to illustrate how the hedonic approach is used when examining the market for environmental goods.

A good example of a study that uses a cross-sectional data set is by Graves et al. (1988). They use sales data from southern California in 1979 to examine the impact of air quality on house prices. The data are matched with characteristics of the house (age, number of bathrooms, square feet, pool, fireplaces, view, air conditioning), the neighborhood (distance to the beach, census tract level information on time to work, percent white, and distance to the CBD), and the community (lot size, crime index, and dummy variables for the county). The environmental variables were measures of visibility and of total suspended particulates (TSP).

The authors focus on several econometric issues: What variables are included and excluded, the impact of measurement error in the variables, the choice of functional form, and various assumptions on the error terms. They report that in a variety of combinations of the independent variables, the TSP coefficients ranged from -0.004 to -0.012 and that the coefficients were always statistically significant. Since the authors do not report how TSP is measured, the estimated coefficients cannot be translated into dollar value impacts on property values. However, this study does find that better air quality will increase the values of homes in an area.

An example of a study that uses time series data is by Kiel (1995). She examines the impact of the discovery of a Superfund site on local property values by collecting sales data from the town of Woburn, Massachusetts. The site was first called to the EPA's attention in 1977, so the data cover the period 1975 though 1992. The equation estimated is:

$$\begin{aligned}\ln(P_i) = \beta_0 + \beta_1(SQFT_i) + \beta_2(AGE_i) + \beta_3(AGE_i^2) + \beta_4(STYLE_i) \\ + \beta_5 \ln(DEFLATOR_i) + \beta_6 \ln(DIST_i) + \varepsilon_i\end{aligned} \tag{6.9}$$

where *STYLE* is an indicator variable of the style of the house (ranch, cape, etc) and *DIST* is the distance in miles from the house to the edge of the Superfund site. The data are broken into six periods defined by the amount of information available to the public at the time.

Kiel reports that, when the site was first examined by the EPA, a one-mile increase in distance from the site increased home values by $1,854 (all in nominal dollars). That impact fell to $1,377 in the period when the EPA put the site on the National Priorities List, and increased to $3,819 per mile in the period when the cleaning of the site was publicly discussed, increased again to $4,077 when the cleaning of the town's wells was discussed, and rose again to $6,468 when the cleanup began. These results suggest that either there exists a stigma for the properties close to the sites in that town, that buyers did not believe that the site would be completely cleaned, that there is a delay in the impact of information on local house prices, or that the housing market in that area has not yet returned to equilibrium.

There are several good examples of studies that use repeat-sales models. Palmquist (1982) chooses to use the repeat sales approach to estimate the impact of highway noise on houses in Seattle sold between 1958 and 1976. He discusses the problems with hedonic models including data requirements in terms of quantity and level of disaggregation and choice of functional form. The repeat sales equation he uses is based on Bailey et al.'s (1963) work and is as follows:

$$\ln(P_{it} / P_{it-1}) = -\ln(B_{t-1}) + \ln(B_t) + \gamma(N_{it} - N_{it-1}) + (\varepsilon_{it} - \varepsilon_{it-1}) \tag{6.10}$$

where P is the price of house i at the time, t, of each sale, B is a "true but unknown real estate price index at the time of the sale" (page 336), N represents the environmental variable, and ε is the error term. The use of B allows the model to control for depreciation between the sales; Palmquist uses 0.76% as the rate of depreciation. He compares his results to those from a hedonic study done on the same area and gets statistically identical results, with information only on the sale dates and the level of noise at each date.

Mendelsohn et al. (1992) use repeat sales analysis to study the impact of PCB pollution on houses in the New Bedford, Massachusetts area. They develop two hedonic equations, one for each time period in which the house sold. They then difference the two equations, which yields the following equation:

$$V_t - V_{t-1} = \beta_1(x_{1t} - x_{1t-1}) + \ldots + \beta_k(x_{kt} - x_{kt-1}) + \varepsilon_t - \varepsilon_{t-1} \tag{6.11}$$

where V is the value of house i in each of the sale periods, t, and the x's (x_1 – x_k) measure k housing characteristics that have changed between the two sales periods. The authors assume that the error term follows a random walk. They also present results based on the fixed effects model, which they show is equivalent to a first difference model corrected for serial correlation induced by multiple sales for a single house with generalized least squares (GLS.)

The authors include a variable that controls for improvements made to the house between sales, changes in the SMSA's income, and changes in interest rates. They also include a variable for the length of time between sales multiplied by a dummy variable for how close the house is to the contaminated harbor, and a variable for whether the pollution event occurred between sales multiplied by the distance dummy variable. They find that prices fall by between \$7,000 and \$10,000 (1989 dollars) for houses located near the harbor.

Gayer et al. (2000) use a repeat sales model to examine the impact of changes in the information on risk due to seven Superfund sites on house prices in the Grand Rapids, Michigan area. The model they estimate is:

$$\ln(P_{it} / P_{it-1}) = \sum_{j=1}^{T} bx_j + \beta_1(RI_{it} - RI_{it-1}) + \beta_2(RISK_{it} - RISK_{it-1}) + \beta_3(NEWS_t - NEWS_{t-1}) + (\varepsilon_{it} - \varepsilon_{it-1}), \tag{6.12}$$

where P is as before, x_j is a dummy variable that takes on a value of 1 if it is the last sale of the house, -1 if it is the first sale, and 0 otherwise. In this equation, *RI* is a dummy variable that takes on a value of one if the house was sold after the EPA's Remedial Investigation of the site closest to the house and zero otherwise, *RISK* is a measure obtained from the EPA's publicly available risk information, and *NEWS* measures the total number of words published in the local newspaper about the Superfund sites from 1985 through the sale of the house. Gayer et al. (2000) find that information released by the EPA on the risk from the site combined with newspaper publicity increased house values on average by \$1,900.

In another paper, Gayer and Viscusi (2002) examine the impact of information about toxic sites on house values. They examine sales prices of houses that sold at different points during the EPA discovery process and use only those homes that sold both before and after some particular change in information (e.g. NPL listing). They then take the ratio of the two sales prices so that all the time invariant characteristics (including distance from the Superfund sites) drop out and only the characteristics that changed during the two points in time, such as information, remain.[ii] Thus the equation they estimate is:

$$\ln(P_{it} / P_{it-1}) = \sum_{j=1}^{T} x_j + \beta_3 (NEWS_{it} - NEWS_{it-1}) + \varepsilon_{it} - \varepsilon_{it-1} \tag{6.13}$$

where t and t-1 indicate the time periods and the x's are indicator variables that take on a value of 1 if it is the period of the second sale, and -1 if it is the period of the first sale, and 0 otherwise.

In examining the Grand Rapids, Michigan area from 1988 through 1993, the authors report that information available to the residents in the local newspaper increased local house prices by $60 to $90 on average. This approach is useful for studying changes in the local environment, such as changes in information or changes in local air quality.

Parsons (1992) uses a similar approach to study the impact of changes in environmental regulations on house values. He examines houses that sold both before and after land use regulations were put in place in Maryland. Some of the houses are in areas that are affected by the regulations, while others are in 'control' areas that are not impacted by the regulations. He eliminates houses that have had observable structural changes, and then develops the following equation of the percentage change in the price of the house:

$$(\alpha P_{it} / P_{it-1}) = (\beta_{it} / \beta_{it-1})[(1+\delta_{Lt})/(1+\delta_{Lt-1})]^{AREA} * \exp(\delta_{St} - \delta_{St-1}) \ln(DIST) * \exp(\varepsilon_t - \varepsilon_{t-1}) \tag{6.14}$$

where P is the price of the house, t-1 is the period prior to the regulations, t is the period after the regulations, α is an estimate of depreciation, $AREA$ is a vector of dummy variable that indicate the extent of the land regulations, $DIST$ is the distance from the most restricted area (equals zero if the house is in the most restricted area), and ε is the error term. The logarithm of the equation is taken, and the resulting model is estimated. Parsons reports finding that areas with land use controls see larger price increases than do areas without controls, and that the closer a house is to a controlled area the larger the price increase.

An example of a study that examines the impact of multiple environmental features on house prices is by Clark and Nieves (1994). They utilize the approach developed by Roback (1982) and Blomquist et al. (1988) that examines the impact of externalities on both wages and house prices. The argument is that a household can be compensated for living in an area with negative (positive) externalities by receiving lower (higher) house prices and/or higher (lower) wages. Thus, it is important to model both impacts in order to correctly calculate the marginal price of the externality.

Clark and Nieves (1994) use data from the 1980 census on wages and 'annual housing rent equivalent' for homeowners. In the house price equation they control for bedrooms, bathrooms, the age of the house, and other structural characteristics. They also include neighborhood and regional characteristics. The environmental variables included are the number of eight different noxious facilities per 1,000 square miles in the county, where the facilities are: Nuclear power plants, coal-fired power plants, gas- or oil-fired power plants, chemical weapons storage sites, Superfund sites, petrochemical refineries, radioactive contaminated sites and liquefied natural gas storage sites. The wage equation includes the worker's experience, education, gender, marital status and race, as well as industry and occupational indicator variables. The noxious facilities variables are also included.

The regressions are estimated using 45,899 housing units and 23,735 individuals. In the housing equation the coefficients generally have the expected sign. The noxious facilities variables are negative and statistically significant except for those on hazardous waste sites and liquefied natural gas facilities, which are positive and significant. The authors suggest that this may be due to the date of the study (1980) when many people may not have been aware of the problems caused by these sites. In the wage equations the noxious facilities' coefficients are all positive, although three are not statistically significant.

In order to calculate the price of each facility, the authors use a weighted sum:

$$P = WAGE * k * (d\ln(R)/dA) - WAGE * (d\ln(W)/dA) \tag{6.15}$$

where k is the fraction of income spent on land and the derivatives of the regressions are as discussed above. The prices on the facilities range from \$58.48 for hazardous waste sites to -\$267.88 for petrochemical refineries in 1980 dollars.

6.6 Conclusion

Hedonic analysis is a useful tool in assessing the dollar impacts of environmental externalities by examining house prices. Since the data can come from actual housing market transactions, the estimated prices from a correctly specified model will reflect individuals' true values for the various components. As data on housing become more accessible, it is not surprising that we have seen an increase in the number and complexity of studies employing the hedonic model to find prices for environmental goods. Various reviews of existing empirical studies show similarities in the results for several types of environmental externalities, which suggests that the approach is a reasonable one, at least in some situations. A great deal of progress has been made in answering researchers' questions, yet some puzzles remain unsolved.

The assumptions that underlie the model—that the housing market is in equilibrium, that all buyers and sellers know all the characteristics of the house and neighborhood, that there is no discrimination in the market, and that the market is not segmented—are not always easily justified in an empirical study. Work remains to be done on how to test these assumptions and what a researcher can do if the assumptions are not met. Of particular interest in the case of environmental goods, the role of information in the market has not yet been fully tested. Researchers often assume that, due to newspaper articles or other public attention, all buyers are aware of the existence of local environmental externalities. However, since realtors are often not required to inform individuals about such problems, it is up to the buyer to discover such sites on their own. How diligent buyers are remains an interesting question.

Researchers also struggle over what variables to include in the regressions: In particular, how best can we measure environmental goods. In theory, we want to include the measure that house buyers observe and that they are most concerned about. In some instances the measure seems clear (e.g. distance to a toxic site) but in other cases it is not (e.g. air pollution). Do individuals care about a single pollutant, or are they more aware of the overall level of all pollutants? Do they think about the past levels of pollution, the current levels, or do they attempt to forecast pollution over the time they plan on owning the house? To answer these questions it is likely that economists will need to work with researchers from other disciplines such as psychology. At this point in time, we can only hope that our scientific measures of pollution will approximate the measures that individuals focus on when buying a house.

The problem of multicollinearity among environmental variables has not been solved. Theory tells us that all relevant variables must be included in the regressions, but when the variables are closely related a new problem arises. The work by Bowen and Kiel (2000) and Kiel and Bowen (2000, 2002) suggests that the relationship between environmental variables may be quite complex. Principle components analysis is a possible approach, which might be relevant if individuals consider all pollution sources together. If that is not the case, then perhaps more sophisticated econometric techniques will be required to solve this problem.

Finally, we need to continue to examine how transferable results are. Are all toxic sites the same? Do all urban areas respond to changes in air pollution in similar ways? The work by Kiel and Williams (2003) suggests that each Superfund site is unique so transferring results may be problematic. More work will need to be done on other types of environmental problems.

As the data become more available, and the sophistication of econometric techniques grows, these questions and many more will surely be answered. Researchers should continue to utilize the hedonic approach to estimate the prices of environmental goods and to calculate the benefits from increasing environmental quality.

Endnotes

[i] They do not report on how they obtained the housing characteristics at the time of each sale, but they seem to come from the multiple listing service that provided the sales price and date.

[ii] Ten of the studies deal with hazardous waste or NPL sites, nine studies examine landfills or incinerators, one on a coal-fired electric utility, one on an existing nuclear power plant, one on chemical facilities, one on multiple facilities, and two on events.

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