On the Issue of Functional Form Choice in Hedonic Price Functions: Further Evidence

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ABSTRACT / Historically, researchers applying the hedonic technique devoted little effort to testing alternative functional forms. This study used Box-Cox transformations on a hedonic model examining property value effects of a closed landfill to help select among alternative functional forms. Although this particular application found that a log-log functional form was appropriate, it appears that functional form may vary by problem and case study area selected. Benefit estimates generated using the hedonic technique may be substantial over- or underestimates if the incorrect functional form is chosen. Proximity to the landfill had no significant effect on property values.

Since its earliest uses in property value studies in the late 1960s, the hedonic method has proven to be an effective tool for estimating the effects of changes in environmental quality on housing prices and has been used to value shoreline, proximity to greenbelts, self-insurance, and air quality changes, to note only a few applications. However, most previous studies have focused on the issues of problem specification, data collection, variable definition and selection, and welfare changes; only relatively recently have researchers turned to the issue of appropriate functional form for the hedonic price function. This paper attempts to add to the literature on functional form selection by using flexible functional forms in a case study of the effects of landfill (dis)amenities on local property values to ''let the data speak'' and, using these results, points out the potential problems in benefit estimation that might result if the incorrect functional form is chosen.

The first section provides a brief overview of methods of nonmarket valuation, highlighting the hedonic method. The second section discusses past treatment of the functional form issue. The third section details the approach used in this study, using a variation of the Box-Cox transformation to determine the appropriate form for the dependent variable and the independent variable of interest. The fourth section applies this technique in a case study of the effects of a nearby landfill on housing prices in Belchertown, Massachusetts. The final section discusses the results and implications of the study for future research.

KEY WORDS: Hedonics; Functional form; Box-Cox; Landfills

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The Demand for Nonmarket Goods: What Constitutes Value?

For many consumer goods, value is relatively simple to estimate: faced with prices in the marketplace, the consumer buys or does not buy, depending on personal valuation of the good. However, environmental or natural resources often have intangible values that are not reflected in market behavior, and so are often considered ''nonmarket'' goods. Total value of a good can be viewed as having eight components derived from use and nonuse values: Total value = use + nonuse = (consumptive + nonconsumptive use) + (option + quasioption) + (existence + intergenerational bequest + interpersonal bequest + Q-altruism). Consumptive use value comes from physically using (and using up) a resource—hunting, eating, etc. Nonconsumptive use value involves using the resource but not depleting it (taking pictures, sightseeing). Option value involves preserving the right to use the resource in the future—a form of insurance in case we might want to use the resource in the future (Freeman 1993). Quasioption value involves waiting to make use decisions until more information is available—another means of risk reduction (Arrow and Fisher 1974). Existence value is the personal satisfaction just from knowing that the resource exists (Freeman 1993). For example, an individual might derive pleasure from knowing that the Grand Canyon is free of dams and development, even though he/she never intends to visit it. Bequest value is the satisfaction of knowing that future generations or others of the current generation will have access to the resource. Finally, Q-altruism is the belief that the resource itself enjoys its own existence separate from humans (Randall and Stoll 1984). For many resources (e.g., endangered species) their worth lies in the less conventional notions of value.

Since market prices do not always reflect the full values of environmental amenities, methods have been developed that attempt to place monetary value on the extra market benefits of these resources. One of these techniques, known as the contingent valuation method (CVM), is based on surveying individuals directly about how they would behave in a hypothetical market situation (Cummings and others 1986). CVM has been used for valuation of various endangered species and a multitude of other commodities (see, e.g., Mitchell and Carson 1989, Stevens and others 1994, Samples and others 1985, Brookshire and others, 1983, Stoll and Johnson 1984). The travel cost method has also been used to derive values on a per-day basis for various types of recreational and wildlife-related activities, such as tourist demand for a saltwater beach day (Bell and Leeworthy 1990, Walsh and Loomis 1985).

The method of interest in this paper for divining the shadow value of unpriced environmental commodities is the hedonic technique, as first proposed by Lancaster (1966) and expanded upon by Rosen (1974) and Freeman (1974). This technique essentially breaks goods down into their characteristics or attributes and consequently is able to generate an implicit or shadow price for the attribute. While the hedonic method has been criticized for its assumptions, inability to capture off-site benefits, and difficulty in isolating marginal changes, it nonetheless provides a valuable tool for valuing certain types of environmental improvement or degradation.

The technique has been used in the past to determine the implicit price of nonmarket goods, ranging from air pollution to historic districts to traffic externalities, and consequently to derive benefit estimates for changes in availability or quality of these goods. However, value estimates may well be affected by the functional form chosen when building a statistical model. One purpose of this paper is to determine, using a case study of landfill proximity effects on property values, whether the choice of functional form will affect these benefit estimates.

The Functional Form Issue in the Hedonic Model

Historically, researchers applying the hedonic technique have spent considerable time on issues of specifying the hedonic relationship and selecting appropriate variables, but little effort on alternative functional forms (Milon and others 1984). Early researchers typically experimented with several functional forms (usually linear, logarithmic, or semilog), then selected among these forms on the basis of goodness-of-fit criteria (Freeman 1993, Cropper and others 1988). However, use of the linear form effectively imposes independence on the explanatory variables chosen, while in a log form parameter estimates make the implicit prices of characteristics dependent upon the levels of other characteristics. These effective restrictions may not hold and may even bias study results; Milon and others (1984, p. 386) found that ‘‘linear or logarithmic restrictions on functional form would severely underestimate the welfare loss’’ involved in their study of shoreline accessibility. In any case, the question of functional form may be answered by the data itself.

Freeman (1993) notes that Goodman (1978) was the first to apply the Box-Cox transformation of the dependent variable in a hedonic study. Essentially, the Box-Cox form provides a means of generalizing the linear model and provides a statistical basis for choosing among different functional forms. Goodman’s approach was still somewhat limited in possibilities, however, since he did not consider alternative forms for the independent variables. More recently, researchers have recommended allowing both for transformation of the dependent variable and for different transformations of each independent variable, although as Freeman (1993, p. 381) notes ‘‘it is not feasible to estimate this form for any realistic number of characteristics’’; Greene (1993, p. 332) goes further, noting that allowing the transformation parameters to differ for the dependent and independent variables is ‘‘usually taken to be more cumbersome than necessary.’’ Palmquist (1991) recommends circumventing this problem by focusing only on the dependent variable and the independent variable(s) of interest. Milon and others (1984) used a variant of this approach in a study of water-related amenities; however, the authors of this study did not allow for any transformations of the nonwater amenity variables, effectively restricting the behavior of their coefficients.

The General Model

The theoretical bases for the hedonic technique have been extensively documented elsewhere and will not be reproduced here; a thorough overview can be found in Freeman (1993). The general hedonic model for housing prices is of the form

$$P(A) = f(S, N, E) \tag{1}$$

where P is sales price, A the attributes or characteristics of the dwelling, S is a vector of structural characteristics such as lot size and square footage, N is a vector of locational and neighborhood characteristics such as accessibility, and E is a vector of environmental characteristics such as proximity to (dis)amenities, air quality, etc. Estimates of the marginal implicit price of the environmental characteristic in question

$$\hat{P}_i = \delta P(A) / \delta E_i \tag{2}$$

are then used to construct an inverse demand function for the environmental "good."

In choosing functional forms for equation 1, an appeal to theory can sometimes be useful. However, for the hedonic model, the only guidance provided is that the first derivative of the price function with respect to the environmental characteristic be negative (positive) if the characteristic is a "bad" (good). Thus, other avenues for divining functional form must be explored.

The Box-Cox transformation (Box and Cox 1964) provides a statistical basis for choosing among various functional forms. The general form of the process is (Johnston 1984):

$$Y^{\alpha 1} = \begin{cases} \dfrac{Y^{\alpha 1} - 1}{\alpha 1} & \alpha 1 \neq 0 \\ \ln Y & \alpha 1 = 0 \end{cases}$$

$$X^{\alpha 2} = \begin{cases} \dfrac{X^{\alpha 2} - 1}{\alpha 2} & \alpha 2 \neq 0 \\ \ln X & \alpha 2 = 0 \end{cases}$$

where Y and X are the dependent and independent variables, respectively. This form can be adapted for the hedonic technique following Milon and others (1984) as follows:

$$P^{\alpha 1} = \beta X^{\alpha 2} + \epsilon \tag{3}$$

where X is a matrix of attribute levels, β is a vector of estimated coefficients, and ϵ is a normal, independently distributed error term. Equation 3 can be further generalized by freeing $\alpha 2$ to differ for each of the different independent variables.

The Box-Cox transformation will be applied to the data so as to allow variation in the functional form of the dependent variable, the environmental variable, and all other independent variables. Results are then compared with the two functional forms most frequently used, linear and logarithmic. In this way, some light may be shed on estimation errors that may occur by forcing a particular functional form on the data.[1]

[1]Of course, it may be that the flexible functional form provides clear evidence that the linear or logarithmic form is perfectly appropriate.

Case Study: Effects of Landfills on Local Property Values

While waste production in the United States totals nearly 200 million tons per year, the number and capacity of landfills—the traditionally preferred method of disposal—have been shrinking in recent decades (USEPA 1990). Despite the need for new waste management facilities, local opposition or the NIMBY (not in my backyard) syndrome has stymied many siting attempts. Recent studies have consistently found that the major concerns regarding these new neighbors are water quality degradation and property devaluation (Whitcomb and others 1994). Thus, from a policy perspective it is useful to determine empirically if indeed landfills do have a negative impact on local property values. However, given that most of the landfills that have closed or will be closing in the United States are small town dumps, it is also of interest to examine whether these small, closed facilities will have residual effects on local property values.

Past empirical evidence on the impacts of landfills on nearby property values is decidedly mixed. Havlicek and others (1971) analyzed 182 single-family house sales between 1962 and 1970 surrounding four landfills in the Fort Wayne, Indiana, region. Their variables of interest were both the linear distance from the nearest landfill and the deviation (in absolute degrees) from the prevailing downwind direction from the landfill. Both the distance and the wind variables were of the hypothesized sign; both were significant at the 5% level. Their results indicated that for each degree away from downwind, the value of the house increased by about \$10.30. For each foot of distance away from the site, price increased by about \$0.61 in a linear fashion.

Nelson and others (1992) estimated the effect of one landfill in Minnesota on 708 surrounding property values. They found that the landfill had a large negative effect on property values of about 12% at the landfill's boundary and of about 6% one mile away.

Hite (1995) used a year of real estate transaction data to determine the effects of distance from three landfills on properties in Ohio. She discovered that, as hypothesized, distance had a positive effect on the property values studied. However, she also attempted to differentiate between the life expectancies of the landfills. She found that the life expectancy of the landfill did make a difference in the size of the landfill's effect on property values.

Zeiss and Atwater (1989) studied the effects of a 200-acre landfill in Tacoma, Washington. They ran a regression on 665 residential properties sold between 1983 and 1986. There were three distinct neighborhoods within the area, leading the authors to run three separate regressions. Their results were statistically insignificant at the 5% level in two of the three cases; in the remaining case, the results were statistically significant, but indicated that the landfill had a positive effect on the surrounding property values. In that case, a new development complex had been constructed directly adjacent to the landfill.

An annotated bibliography prepared by Clarion Associates (1991) shows that of six regression analyses of property values, one found that the landfill had a negative effect on property values, four found no evidence of an effect, and one found a positive effect. Another survey by Zeiss and Atwater (1989) showed six cases that confirm a negative effect, eight cases that show no effect, and one case showing a positive effect.

All of the landfill studies to date have been done in urban or heavily populated areas. However, sanitary landfills located in rural areas are deserving of attention as well. Currently, many landfills located in rural areas are closing as small towns consolidate their municipal waste. Many small towns, especially in New England, are growing rapidly. In many of these towns, the only land that remains undeveloped is the land surrounding the landfill. Therefore it is necessary to study the effects (if any) of small, closed landfills as well as open, operating ones on the surrounding property values.

The Study Area

The study area chosen was Belchertown, Massachusetts (1990 pop. 10,579), located 15 miles southeast of Springfield, Massachusetts. The Belchertown landfill, a small, town-owned, lined facility, accepted 1100 tons of waste in 1991 and was subsequently closed, with final capping to be completed in 1996. Although the town was assessed a civil administrative penalty of $1500 in 1988 by the Department of Environmental Quality Engineering, a recent inspection did not reveal any problems with leachate.

Data for the study were collected from Multiple Listing Service files and town records of single-family home sales between January 1992 and August 1995. Transactions within a two-mile radius were selected based on previous research, which indicated little or no impact beyond the two mile limit (Nelson and others 1992), and the assumption that if property value impacts did not occur within the two mile radius, they certainly would not occur beyond it. The 103 individual parcels were then plotted on US Geological Survey topographic maps to determine distance from the Hamilton St. landfill, distance to the central business district,[2] and the nearest primary highway.

The Hedonic Price Function

Independent variables in hedonic property value models generally fall into three categories: structural, neighborhood, and environmental (Freeman 1993). However, variables must also be selected with an eye toward avoiding the problem of collinearity. Using these guidelines and drawing upon past studies, linear distance to the landfill was selected as a proxy for the disamenities created by the site. Neighborhood characteristics chosen were distance to the central business district and distance to the highway, in miles. Structural characteristics were age of the house (as a proxy for condition), number of rooms, lot size, and the presence or absence of garages (s), fireplace, or swimming pool.

Following the Box-Cox form developed previously in equation 3, the hedonic price function incorporating the effects of landfill proximity can be defined as follows (0–1 variables are not transformed):

$$\begin{aligned} P^{\alpha 1} = {} & \beta_0 + \beta_1\, MLFILL^{\alpha 2} + \beta_2\, MCBD^{\alpha 2} + \beta_3\, MHWY^{\alpha 2} \\ & + \beta_4\, AGE^{\alpha 3} + \beta_5\, RMS^{\alpha 3} + \beta_6\, LTSIZE^{\alpha 3} \\ & + \beta_7\, GARG1 + \beta_8\, GARG2 + \beta_9\, FP \\ & + \beta_{10}\, POOL + \beta_{11}\, (MLFILL^{\alpha 2})^2 \\ & + \beta_{12}\, (MCBD^{\alpha 2})^2 + \beta_{13}\, (MHWY^{\alpha 2})^2 \end{aligned}$$

where *P* is the sales price, 1995 dollars; *MLFILL* is the distance to landfill, in miles; *MCBD* is the distance to central business district, in miles; *MHWY* is the distance to highway, in miles; *AGE* is the age of house, in years; *RMS* is the number of rooms; *LTSIZE* is the lot size, in acres; *GARG*1 is 1 if house has a one-car garage, 0 otherwise; *GARG*2 is 1 if house has a two-car garage, 0 otherwise; *FP* is 1 if house has a fireplace, 0 otherwise; *POOL* is 1 if house has a pool, 0 otherwise; $MLFILL^2$ is the distance to landfill, squared; $MCBD^2$ is the distance to central business district, squared; $MHWY^2$ is the distance to highway, squared[3]; and αi is the power transformation parameter.

Although this form of the Box-Cox process limits the amount of information yielded on the nonlandfill characteristics (since all are constrained to have the same value for $\alpha 3$), it does provide information on the landfill variable parameter and, as Cassel and Mendelsohn (1985) have pointed out, the estimate of the marginal implicit price of this characteristic is of prime

[2]The Belchertown town hall was selected as the ‘‘central business district’’ of this largely rural town.

[3]The three quadratic terms were suggested by experimenting with the various Box-Cox specifications.

interest. Specifically, in order to reduce the number of parameters to be estimated (following Greene's advice), three values of α were used: α1 for the dependent variable, α2 for the various location variables (distance to landfill, highway, and central business district), and α3 for all other independent variables.

Results

A variety of functional forms were tested,[4] in addition to quadratic and nonquadratic forms of the explanatory variables on distance. The linear and double log forms are presented in Table 1, along with the most promising Box-Cox transformation (confidence intervals are not listed for the Box-Cox transformation, since the procedure tends to inflate the standard errors). Examining the likelihood ratios, the Box-Cox results clearly reject the linear model. However, the Box-Cox results are very similar to the double log model, which indicates that in this example, selection of this functional form would have yielded reasonably accurate results. Using chi-squared likelihood ratios for the linear and double log models nested in the single-α Box-Cox model, the likelihood ratio statistic is $2 * (1157 - 1140) = 34$, while the double log has a likelihood ratio statistic of 1.18 (critical chi-squared value is 3.8).

The final Box-Cox model selected resulted in α values of 0 (indicating a logarithmic transformation) for the dependent variable, 0 for the landfill and other distance variables, and 0.25 for the remaining independent variables concerning the size of the house. The α value associated with the landfill variable parameter should not be scrutinized too heavily, however, since its (MLFILL's) coefficient was not statistically significant.

Implications for Landfill Siting

Regarding the specific problem of the case study, it is interesting to note that proximity to the landfill did not appear to have any effect on housing values in any of the forms examined. This could be interpreted several ways: closed landfills have no effect on property values; the small size of this particular landfill tends to minimize its effect on property values; or homebuyers were unaware of the site, since it was not in operation at the time of the sale. Since the landfill coefficient was not statistically significant, no estimates of welfare losses were derived for any of the models for comparison.

Principal variables affecting the price of the houses in the data set were number of rooms, lot size, and presence of a garage, as well as miles to the central business district squared. This last locational variable coefficient indicates that there is a nonlinear relation-

Table 1. Maximum likelihood estimates of hedonic price function, alternative Box-Cox specifications

Variable	Linear specification coefficient (standard error)	Double log specification coefficient (standard error)	Box-Cox specification coefficient (standard error)
CONSTANT	−2,044.04	10.304[b]	10.731
	(19,991.84)	(0.277)	(0.438)
MLFILL	16,674.74	0.042	0.044
	(12,598.65)	(0.037)	(0.037)
MCBD	21,053.04[a]	0.022	0.019
	(11,994.32)	(0.036)	(0.036)
MHWY	9,746.44	−0.011	−0.012
	(12,790.86)	(0.037)	(0.037)
AGE	−61.07	−0.047[b]	−0.022
	(67.55)	(0.015)	(0.023)
RMS	13,586.39[b]	0.614[b]	0.387
	(2,005.47)	(0.090)	(0.242)
LTSIZE	0.14[b]	0.042[a]	0.004
	(0.05)	(0.024)	(0.013)
GARG1	−5,373.97	−0.023	−0.025
	(5,837.28)	(0.041)	(0.041)
GARG2	13,201.71[b]	0.096[b]	0.090
	(6,237.86)	(0.043)	(0.043)
FP	−5,910.23	−0.042	−0.044
	(4,744.87)	(0.033)	(0.033)
POOL	10,216.00	0.076	0.070
	(10,019.80)	(0.071)	(0.070)
$MLFILL^2$	−3,096.98	0.020	0.016
	(3,643.41)	(0.028)	(0.028)
$MCBD^2$	−5,226.59[a]	−0.080[a]	−0.075
	(2,818.85)	(0.041)	(0.041)
$MHWY^2$	−4,357.85	−0.010	−0.009
	(5,464.17)	(0.010)	(0.009)
α1	1.00[c]	0.000[c]	0.000
	(NA)[d]	(NA)	(NA)[e]
α2	1.00[c]	0.00[c]	0.000
	(NA)	(NA)	(NA)[e]
α3	1.00[c]	0.00[c]	0.295
	(NA)	(NA)	(0.331)
Log Likelihood	−1,157.36	−1,140.01	−1,139.42
R^2	.64	NA	NA
N	102	102	102

[a]Statistically significant at 95% level.

[b]Statistically significant at 99% level.

[c]Imposed by assumption of linear of logarithmic form.

[d]NA = not applicable.

[e]Standard errors not available since estimate is on the boundary.

[4]Specific forms tested were with / without quadratic terms for the three distance variables (MLFILL, MCBD, MHWY); different power transformation (α) values for the dependent variable and MLFILL; power transformation values for the dependent variable of α1 with all independent variables with power transformation value of α2; and α value set to 0 for dependent variable, α2 for MLFILL, MCBD, MHWY, and α3 for AGE, RMS, and LTSIZE. These results are available from the authors.

Table 2. Effects of various functional form specifications on landfill distance variable coefficient estimates

	Coefficient estimates (standard errors)		
Variable	Linear	Linear with quadratic terms	Double log
MLFILL	3,402.14 (4,214.21)	16,674.74 (12,598.65)	0.042 (0.037)
$MLFILL^2$	N/A	−3,096.98 (3,643.41)	0.020 (0.028)

ship in proximity to the town hall; that is, one wants to be close to town but not too close.

Implications of "Incorrect" Functional Form

As noted previously, many studies have simply chosen a convenient functional form arbitrarily or on the basis of crude goodness of fit measures. Our results point out potential pitfalls of this practice.

The consequences of choosing a "naive" linear model (that is, a model with no quadratic terms) on the variable of interest (*MLFILL*), as compared to the less naive model with quadratic terms added (linear/quadratic) and the double log model, are illustrated in Table 2. As the results illustrate, compared to the naive linear model, the standard errors of the landfill variable coefficient are reduced considerably in the linear quadratic and double log models. It is thus possible that selection of a simple linear form would overlook statistically significant relationships.

If the linear/quadratic specification were chosen (as used by Nelson and others 1992), quite different results would obtain as compared to the double log specification supported by the Box-Cox procedure. Comparing the independent variables of the double log and linear models, two coefficients (excluding the constant) differ in statistical significance: the coefficient of *MCBD* is significant at the 95% level in the linear specification but is not statistically significant in the double log model, while the AGE variable coefficient is significant at the 99% level in the double log model but is not significant in the linear model. In addition, coefficient magnitudes tend to differ between models, affecting both forecasting and interpretation (of course, coefficients between the linear and double log forms cannot be directly compared since the latter are elasticities while the former are simply marginal changes). This again reinforces the need to pay close attention to issues of functional form.

Finally, differences in benefit estimates between alternative functional forms should be considered. Again using the linear/quadratic and double log models for comparison, benefit estimates could differ widely depending on form chosen. Using the *RMS* variable[5] (which was statistically significant in both models) for comparison, an increase of one room in the average household would result in an increase of $13,586.39 in the house's selling price in the linear/quadratic model, as compared to $12,352.27 in the double log model, a difference of $1234.11 or nearly 10%. These differences in estimates would be even greater for observations further from the mean variable values. Clearly, this demonstrates the pitfalls that could be encountered in using these estimates for policy development. In addition, the bias introduced in benefit estimates may be indeterminate; that is, it is unclear whether choice of the "wrong" form would lead to over- or underestimates of the true benefits.

Concluding Remarks

This exploratory analysis sheds additional light on the selection of functional form for hedonic price studies. These results indicate that, for the case study used, a double log specification would yield appropriate results. This is in contrast to the results of Milon and others (1984), which conclusively rejected the double log form. Further, the linear form used by Nelson and others (1992) may or may not have been appropriate; without tests of the appropriateness of the linear model, it is impossible to determine. It seems safe to conclude that different applications of the hedonic technique (and perhaps even different data sets used for analyzing the same basic problem type) may require different functional form specifications. As these results demonstrate, choice of functional form can affect both variable significance and coefficient magnitudes. Thus, the functional form issue should be accorded the same care and attention as issues of variable selection and model specification.

Regarding the landfill issue, a larger data set and multiple case studies would help answer the question of landfill effects on local housing prices. In addition, an analysis of different types of landfills—closed, recently opened, history of environmental problems, no environmental problems, etc.—would provide additional useful, if not definitive, results.

[5]The coefficient of the primary environmental variable of interest (MLFILL) was not statistically significant in any model specification; it was therefore felt that benefit estimate comparisons between models using this variable's coefficient would not be meaningful. The RMS coefficient was thus chosen to address the question of functional form selection and benefit estimation.

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