Estimating the Demand for Protecting Freshwater Lakes from Eutrophication

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In any discussion of the valuation of public goods, particularly environmental amenities, contingent valuation, travel cost, and hedonics are commonly cited as methods for estimating Hicksian or Marshallian welfare (Freeman). While contingent valuation and travel cost are widely employed, we know of very few applications where hedonic demand functions have been estimated. Palmquist (1984) and Parsons estimated second-stage hedonic demands for characteristics of housing units. Both used the approach of estimating separate hedonic price functions for different real-estate markets to identify demand parameters for housing characteristics.[1]

The research reported here is the first to use separate real-estate markets to identify demand parameters for an environmental amenity. The specific application is water clarity in selected lakes in Maine. Reduced water clarity is the physical manifestation of algae blooms caused by eutrophication that is the result of nonpoint pollution (Boyle et al.). The nonpoint pollution is due to agricultural and forestry practices and residential development within lake watersheds. Water clarity is measured using a secchi disk that is 8 inches in diameter and is alternatively black and white in each quadrant. The disk is lowered into the lake water and the depth at which the disk disappears from sight is a measure of water clarity. The minimum water clarity during the summer months, the period of lowest water quality due to eutrophication, is used as the measure of water clarity in the hedonic price functions. Hedonic price functions are estimated for four market areas that are distinguished by being in different multiple listing regions, having different regional characteristics, and by their distances from each other. The implicit prices calculated from the four markets are used to estimate the demand for lake-water clarity in Maine.

Here, we report the estimated demand for lake-water clarity and investigate the effect on own price and surplus measures for three different specifications of demand (linear, semilog, and Cobb-Douglas). Welfare measures are also calculated for two different changes in water clarity. The water-clarity changes are based on the average clarity of lakes without compromised clarity (5.15 meters), the average clarity of all lakes (3.78 meters), and the average clarity on lakes with compromised water clarity (2.41 meters).

Model and Data Description

In the two-stage, hedonic model, the first stage is to estimate hedonic-price functions relating the price of the property to the characteristics of the property, its structure, and its location. For each market area, we estimate: $PP = \Sigma_j \beta_j A_j + \beta_{WC} LKAREA \cdot \ln(WC)$, where PP is the property's sales price, the β's are coefficients, A_j is a vector of property character-

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[1] Chattopadhyay used a closed-form solution proposed by Epple to extract utility parameters from an estimated first-stage, hedonic price function to derive welfare measures for changes in air quality. Palmquist (1991) concludes, however, that "closed form solutions to hedonic models may not be valid...because they are based on questionable assumptions" (p. 86). While the separate market approach appears to be more credible, in that it does not suffer from restrictive utility assumptions (e.g., additive separability of housing characteristics), concerns arise as to what is a distinct market for estimating different hedonics to identify demand parameters. This is not a question for which economic theory provides insight, nor is it an issue that can simply be addressed by conducting parametric tests of hedonics between markets; local knowledge and intuition play an important role.

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istics that are assumed to affect sales prices,[2] *LKAREA* is the total surface area of the lake on which the property is located, and ln(*WC*) is the natural log of the minimum water clarity of the lakes during the summer months of the year in which the property was purchased. Smeltzer and Heiskary indicate that the greater the water clarity, the more difficult it is for individuals to perceive a marginal change in the visibility. To capture this effect, we include the natural log of water clarity in the hedonic-price function. Lake area is interacted with water clarity because they are found to be collinear. Variation in water clarity is obtained by having sales over time for each lake in each market area.

The marginal implicit price of an attribute is given by the partial derivative of the estimated hedonic-price function with respect to that attribute. With multiple markets, the estimated hedonic price coefficients vary across markets, and therefore, so do the marginal implicit prices. Variation in the implicit price of an attribute is necessary to identify the demand curve for that attribute (Palmquist 1984, 1988). The marginal prices, along with the corresponding quantities purchased, are used to estimate the second-stage demand: $Q^i_{WC} = f(P^i_{WC}, P^i_k, Z_i)$, where Q_{wc} is the quantity of water clarity purchased, P_{wc} is the price of water clarity, P_k is a price vector of substitutes and/or complements to water clarity, and Z_i is a vector of demographic characteristics and other factors assumed to influence demand.[3] Three demand specifications are estimated: linear, semilog, and Cobb-Douglas.

Two noteworthy features of our model should be mentioned. First, the specification of the hedonic-price function implies that water clarity is more important to consumers of lakefront properties on larger lakes. As lake area and water clarity are physically related with a positive correlation, a person may be willing to lower their standard for water clarity to locate on a small lake in order to avoid the boat traffic and other activities that occur on larger lakes. Secondly, because the logarithm of water clarity enters the hedonic price function, the marginal implicit price of water clarity is endogenous in the consumer's choice problem. That is, the price an individual faces for water clarity will be a function of their choice of the level of water clarity. Thus, after calculating implicit prices of water clarity for each property sale, we instrument the implicit prices prior to estimating the second-stage demand. In addition, because price is nonlinear, the budget constraint facing the individual will be nonlinear. Palmquist (1988) derives the conditions under which welfare estimates may be obtained in this case. This requires linearizing the budget constraint around the chosen consumption bundle. This linearization adjustment is $I_a = I - PP + PPHat$, where I_a is adjusted income, I is income, *PP* is the sales price of the property, and *PPHat* is the predicted price of the property from the hedonic price function. Adjusted income is also endogenous and must be instrumented prior to estimating demand.

Lakefront property sales for twenty-five lakes in Maine between 1990 and 1995 within four market groups were used to estimate the hedonic model. Market groups were defined by the proximity of the lakes to each other and to a common large community and were in distinct multiple-listing regions. Property characteristics and sale prices were collected from tax records that are maintained at the town offices. Income and personal characteristics were collected in a mail survey of a sample of property purchasers from all market areas. Water-clarity data were provided by the Maine Department of Environmental Protection. Clarity varied substantially across lakes within each market area (table 1). Two market areas had lakes with minimum water clarity during the summer months substantially below 1 meter (Waterville and Camden), while two had lakes with minimum water clarity measures of 8 meters or more during the summer months (Lewiston/Auburn and Bangor). The average price of visibility, as estimated by the first-stage hedonic-price functions, varies from $2,337 per meter (Bangor) to $12,938 per meter (Camden).

Results

The own price of water clarity is negative in the linear, semilog, and Cobb-Douglas spec-

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[2] These characteristics are as follows: the square feet of living area, the feet of frontage on the lake, the number of lots per 1,000 feet of frontage adjacent to the property, distance to the nearest city, whether or not the property has central heating, whether or not the property has a full bath, and whether or not the property's primary source of water is the lake. In two markets, dummy variables were included to highlight lakes that have unique attributes that are not reflected in the attributes specified in the hedonic price equations, for example, large, shallow lakes.

[3] Specifically, the substitutes/complements we consider are the square feet of living area and the lake frontage of the property (in feet). Variables included in Z_i are as follows: the purchaser's income; whether or not a property owner visited the lake before purchasing the property; whether or not the purchaser expected an improvement, decline, or no change in the water clarity at the time the property was purchased; and whether or not friends or relatives of the purchaser also owned property on the lake at the time the property was purchased.

Table 1. Descriptive Statistics for Market Areas

	Lewiston/Auburn (n = 48)	Waterville (n = 112)	Bangor (n = 68)	Camden (n = 21)
Visibility in meters	6.12	4.13	5.39	3.55
	(1.68)	(1.83)	(1.72)	(1.61)
	[3.4–9.4]	[0.4–6.3]	[1.8–8.0]	[0.3–6.4]
Price of visibility	4,235	2,695	2,337	12,938
	{7,625}[a]	{1,743}	{3,566}	{34,680}
	(2,168)	(1,230)	(2,097)	(15,690)
	[1,234–6,866]	[597–5,975]	[435–11,820]	[1,983–71,343]
Property price	104,069	85,880	73,938	100,350
	(65,557)	(55,083)	(49,931)	(115,472)
	[19,000–295,000]	[2,500–350,000]	[400–220,090]	[5,000–500,000]
Income	84,062	77,388	73,823	69,048
	(60,302)	(49,753)	(49,378)	(45,761)
	[7,500–212,500]	[12,500–212,500]	[7,500–212,500]	[22,500–212,500]

Note: Mean values are reported for each variable. Standard errors are in parentheses and the range is reported in brackets.

[a] Price of visibility computed at the average visibility (4.15 meters) and the average lake area (3,514 acres) for all lakes in our sample.

ifications and is significant in the semilog and Cobb-Douglas specifications at the 90% and 95% levels of confidence, respectively. (The p-value on the own-price coefficient in the linear model is 0.15.) The prices of living area and lake frontage are positive and significant at the 5% level in all three specifications, which indicates that these attributes are substitutes to water quality.

Income is not significant in any of the three specifications and the p-values range from 0.28 (semilog) to 0.45 (Cobb-Douglas). Recall from the earlier discussion of the model that income in the estimated demand equation is adjusted and instrumented due to the nonlinear budget constraint. We also estimate each of the specifications of the demand equation without adjusting and instrumenting income, and income becomes significant in all three specifications. It is also interesting to note that not adjusting or instrumenting income results in coefficient estimates for income that are nearly identical in magnitude to those from the equations where income was adjusted and instrumented in the linear and semilog specifications. Own price remains insignificant in the linear specification and becomes insignificant in the semilog specification when income is not adjusted or instrumented. Not adjusting and instrumenting income also affects the magnitudes of the own-price coefficients. In the welfare evaluations reported here, we use the specifications where income is adjusted and instrumented because of the conceptual desirability of this procedure and the influences on the own-price coefficient when income is not adjusted and instrumented.

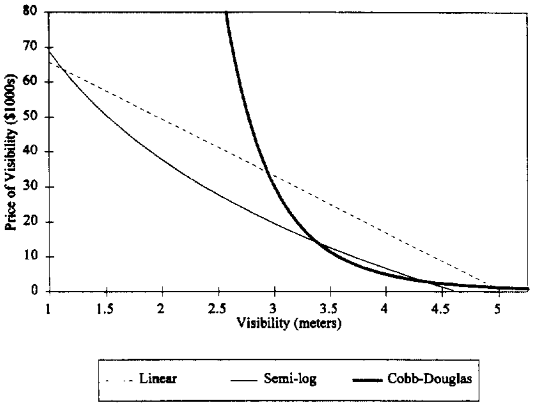

Figure 1. Demand functions for water clarity

Of the personal characteristics in the demand equation, only the variable indicating whether or not the purchaser expected an improvement in water clarity is significant in all three specifications, and whether or not the purchaser had friends or family with properties on the lake is significant in the linear specification (see footnote 2 for other variables). The coefficient on the expected improvement variable is negative in all three specifications and the coefficient on friends is positive.

The demand functions for all three specifications are graphed in figure 1 using grand constants where all variables except own price are evaluated at their sample means and are included in the constant terms. The linear

Table 2. Welfare Measures

Initial Visibility	New Visibility	Consumer Surplus	Percent of Linear Estimate	Percent of Semilog Estimate
Linear model: $P_{wc} = 5.03 - (6.14 \times 10^{-4})Q_{wc}$				
3.78	5.15	\$12,870		
3.78	2.41	\$43,335		
Semilog model: $\ln P_{wc} = 1.53 - (2.22 \times 10^{-4})Q_{wc}$				
3.78	5.15	\$3,765	29.2	
3.78	2.41	\$25,388	58.6	
Cobb-Douglas model: $\ln P_{wc} = 2.73 - (0.158)\ln Q_{wc}$				
3.78	5.15	\$3,677	28.6	97.7
3.78	2.41	\$46,750	107.9	184.1

(dashed line) and semilog (thin line) demand curves intersect the price axis and the quality axis at approximately the same points and only differ in their curvature. The slope of the Cobb-Douglas specification increases dramatically to the left of 3.0 meters. This result is very interesting because the Maine Department of Environmental Protection has determined that 3.0 meters of clarity is the threshold below which lakes have significantly compromised water quality, that is, it is nearly impossible from a management perspective to institute any actions that will improve water clarity. The Cobb-Douglas specification suggests that 3.0 meters is also an important threshold in terms of public preferences.

Another interesting aspect of the significance of the own-price coefficients in the semilog and Cobb-Douglas specifications is that limnologists argue that it is easier and cheaper to protect a lake from diminished water clarity due to eutrophication than it is to restore a lake's water clarity after it has diminished. The nonlinear demand specifications suggest that the benefits of protection exceed those of improvement. That is, for a given level of water clarity, the surplus loss associated with a reduction in clarity (the benefits of protection) exceeds the surplus gain from an equal improvement in clarity.

Different scenarios of water-clarity changes further illustrate the difference in each of the demand specifications. The average visibility for all lakes in Maine is 3.78 meters, the average visibility for lakes that do not have compromised water clarity (>3 meters) is 5.15, and the average visibility for lakes with compromised water clarity (≤3 meters) is 2.41 meters. Assuming a property is located on a lake with water clarity of 3.78 meters, the surplus gain associated with an increase or decrease in clarity is the area under the estimated demand curve between initial visibility and the new visibility (Parsons). For an improvement from 3.78 to 5.15 meters, the calculated surplus is \$3,765 for the semi-log specification and \$3,677 for the Cobb-Douglas specification (table 2). Alternatively, if water clarity were to decrease to 2.41 meters, the welfare losses would be \$25,388 for the semilog specification and \$46,750 for the Cobb-Douglas specification. That is, the surplus associated with the decrease in water clarity is nearly seven times greater than that of the increase in water clarity for the semilog specification, and the ratio is nearly thirteen for the Cobb-Douglas specification.

For the improvement in water clarity, the linear specification has the highest welfare gain followed by the semilog and Cobb-Douglas specifications, and the semilog and Cobb-Douglas specifications have approximately equal welfare gains. For the decrease in clarity, the welfare loss from the Cobb-Douglas and linear specifications are nearly double that of the semilog specification.

Conclusions

The results reported here indicate that, if the assumption of distinct markets is accepted, it is possible to use independent, implicit-price estimates from these markets to identify the demand parameters for an environmental amenity in a second-stage, hedonic demand model. The results are quite promising with own price having the correct sign and being significant in two of the three specifications. Complements are significant in all three specifications. While adjusted income has the correct sign in all three specifications, it is not significant.

We place more credibility in the semilog and Cobb-Douglas specifications, as the coefficient on own price is not significant in the linear specification. In addition, the curvature of the nonlinear specifications is consistent with the perceived notion that reductions in water clarity at lower base levels of clarity (≤3 meters) are more problematic than reductions at higher base levels of clarity (>3 meters). From a policy perspective, the semilog model would provide the most conservative welfare estimates. If 3 meters truly is an important threshold to households, as well as from a limnology perspective, the semilog specification would substantially understate welfare losses for changes below 3.0 meters.

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