Evidence of the Effects of Water Quality on Residential Land Prices

Christopher Leggett and Nancy E. Bockstael
Department of Agricultural and Resource Economics
University of Maryland

Presented August 4, 1998, at the Annual Meeting of the American Agricultural Economics Association

Correspondence should be addressed to:

Dr. Nancy E. Bockstael
Department of Agricultural and Resource Economics
University of Maryland
College Park, MD 20742

Abstract

We use hedonic techniques to show that water quality has a significant effect on property values along the Chesapeake Bay. Mindful of the limitations of using hedonic methods for welfare analysis, we calculate the potential benefits from an illustrative (but limited) water quality improvement. Past hedonic studies have almost entirely ignored the potential for omitted variables bias -- the possibility that pollution sources, in addition to emitting undesirable substances, are likely to be unpleasant neighbors. We discuss the implications of this oversight, and we provide an application that addresses the problem head-on.

Key Words: water quality, hedonic models, residential land prices

Evidence of the Effects of Water Quality on Residential Land Prices

Introduction

Hedonic models are admittedly limited in their ability to yield defensible welfare measures of discrete environmental changes. Estimation of welfare effects of such changes generally involves identifying parameters of preference functions, but identification of these parameters from a single hedonic function is difficult without imposing a large amount of structure on the problem.[1]

Yet, hedonic analyses continue to appear in the environmental economics literature, and for good reason. For one thing, estimation of marginal willingness to pay for changes in an environmental good is possible from the hedonic price function alone. And, in some circumstances, the hedonic price function can provide bounds on welfare measures of discrete changes. Even when marginal values are of little interest and bounds cannot be justified, hedonic analyses are useful if they provide empirical evidence that the price for some heterogeneous market good (generally real property) reflects the level of some environmental good embodied in it. Given the sometimes-elusive nature of environmental benefits, such information is valuable in its own right. It provides evidence that people would be willing to pay more for higher environmental quality and suggests a pathway through which people are affected by changes in the environmental good.

Air quality is by far the most commonly treated environmental good in the hedonic framework. (See Smith and Huang [28, 29] for a meta-analysis of this work)[2]. In contrast, we could find only four hedonic studies incorporating water quality measures published within the last thirty years (David [7], Epp and Al-Ani [11], Feenberg and Mills [12], Steinnes [31]), and only two unpublished studies (Brashares [3], Michael, Boyle and Bouchard [19]). The paucity of work suggests that environmental economists have had difficulty providing evidence that water quality affects property values. It may be that individuals owning waterfront property do not care about the adjacent water quality. But this conflicts with *a prior* expectations. If anyone cares about water quality, one would think it would be the owners of waterfront property, since by purchasing such property they have essentially self-selected for an interest in water related activities.

A more plausible explanation involves the nature of water bodies and their relationship to housing markets. In the case of air quality hedonics, the selection of an appropriate housing market is relatively simple. As long as air quality monitoring stations are densely distributed across the landscape, the researcher has the freedom to define the spatial extent of the market. In contrast, water bodies essentially impose a "market" on the researcher: only the subset of properties that borders lakes, rivers, or estuaries may be analyzed. Thus, researchers are often faced with a difficult tradeoff between variation in environmental quality and the extent of the housing market. A single lake, for example, might limit the housing market appropriately and thus avoid bias, but water quality might not vary sufficiently across the lake. On the other hand, extending either the geographical or temporal domain of the analysis to capture more variation in the water quality variable could extend the study beyond what can legitimately be considered a single market.

Even when appropriate data is available and statistically significant coefficients on environmental quality measures can be obtained in a hedonic regression, the results are often viewed with skepticism. For such results to be convincing, one needs a plausible story of how people would learn about the variation in environmental quality or be able to perceive a proxy for it.[3] In addition, one needs to rule out the possibility that a third factor, correlated in space or time with environmental quality, is not causing the results.

In this paper we attempt to provide evidence of a phenomenon that has been rarely supported in the literature – that water quality has an effect on residential property values. The evidence is based on a particularly fortuitous arrangement of nature – a highly irregular coastline with significantly varying water quality and numerous residential waterfront properties located within a limited area.

In addition, to the extent possible, we account for the possibility that the emitters of pollution may themselves be disamenities. This potentially serious problem has been largely ignored in the hedonics literature. Because emitters cause environmental degradation, air or water quality will be highly correlated with the spatial location of emitters. If the emitters themselves are undesirable, then it will be difficult to separate the effects of environmental quality variation from proximity to emitters.

Hedonic Theory and Empirical Considerations

While hedonic models were estimated as early as Waugh's [32] study of asparagus, tomato, and cucumber prices, Rosen [25] was the first to formalize the theory underlying the market for heterogeneous goods. In the Rosen framework, a quality differentiated good is represented by a vector of the levels of characteristics, $z_1,\ldots,z_n$, embodied in the good. The sales price of any unit of the differentiated good is a function of the levels of these n characteristics. The functional relationship between sales price and characteristics is called the hedonic price schedule, $P(Z)$. This function is increasing in characteristics that are valued by individuals because buyers will bid up the price of units with more of a desirable attribute. The hedonic price function is really a locus of equilibrium prices and arises as a result of the interaction of buyers and sellers in the market for the heterogeneous good. With the possibility of an approximately continuous array of characteristics available in the market, consumers choose levels of all characteristics such that the marginal price of each, $\partial P/\partial z_i$, equals the marginal rate of substitution between each characteristic and a composite good, $\partial U_{zi}/\,\partial U_m$. As a result, if the hedonic price function can be accurately estimated, then the slope of the function with respect to any characteristic evaluated at an individual's choice represents that individual's marginal valuation for more of the characteristic. Just being able to demonstrate empirically that this marginal valuation is positive for some characteristic is often useful information in its own right.

The most common heterogeneous good modeled in this way is real estate or housing. In this case, individuals are viewed as purchasing just one unit of the quality-differentiated good, which greatly simplifies the characterization of the problem. Also, for many active housing markets, the assumption of an approximately continuous array of characteristics, together with accurate information about those characteristics, is not difficult to justify. But while the theoretical story may be quite straightforward, empirical applications in the environmental economics literature are plagued with ambiguities. Choice of functional form is arbitrary, the definition of the extent of the market is problematic, and multicollinearity poses problems for the selection of explanatory variables. Potentially more serious – yet less frequently discussed – is the possibility that omitted variable bias may lead to an overestimate of the environmental quality parameter.

The first problem is generally handled by employing a functional form with at least some flexibility. However, a functional form which is too general may not prove very robust to small misspecifications (see Cassel and Mendelsohn [4]; Cropper, Deck and McConnell [6]). Despite a great deal of discussion, little consensus has been achieved in the literature on a satisfactory approach, and the choice of functional form remains somewhat arbitrary.

An adequate definition for the "extent of the market" has proved equally illusive. From any one individual's perspective, the relevant real estate market is defined by that individual's area of search. If the researcher includes in his model a property that is outside this search radius, then he runs the risk of biasing his coefficients. However, if he does not include the full market, as perceived by the individual, then he is not taking full advantage of all available information and his estimates may be inefficient. We have little way of knowing this search radius for any one individual. Perhaps more serious is the possibility that different individuals' markets may be neither coincidental nor distinct, but actually overlapping. Palmquist [22] has argued that while we may, in general, lose efficiency from including too small a market, if we are searching for the effects of a localized environmental good, we may be better off including only a subset of the housing market in the general vicinity of that good.

Perhaps the most perplexing problems inherent in the application of hedonic analysis are those posed by multicollinearity. While the hedonic literature tends to emphasize the potential for severe multicollinearity among structural characteristics, neighborhood variables are likely to be correlated as well. There may be a strong correlation, for example, between the amount of industry and the amount of high density residential development near any given house. Of course, when some of these collinear variables are omitted from the regression, estimates of the remaining coefficients will be biased. Where the sets of collinear explanatory variables are not themselves the object of interest or where they are all proxies for the same exogenous effect, then selecting a subset of these collinear variables does little harm to the intent of the regression. Unfortunately, such straightforward antidotes to the problem of multicollinearity are not always possible.

Omitted Variables Bias and Direct Emitter Effects

An environmental quality parameter that is robust to the specification issues discussed above is still insufficient evidence for concluding that people care about environmental quality and are willing to pay for it. There is often good reason to suspect that omitted variable bias may be contributing to this statistical significance. Where environmental degradation is caused by emissions from polluters, the spatial distribution of environmental quality may be highly correlated with the spatial location of emitters. If the emitters themselves are undesirable, then it will be difficult to separate the effects of environmental quality variation from the effects of proximity to these emitters. Failure to control for the disamenity effect of the emitter will bias the estimated coefficient on the pollution measure, producing a larger negative estimated effect and making it more likely that the null hypothesis of no effect will be rejected.

In an early comment on the validity of the hedonic approach to environmental valuation, Small [27] writes

> I have entirely avoided in this comment the important question of whether the empirical difficulties, especially correlation between pollution and unmeasured neighborhood characteristics, are so overwhelming as to render the entire method useless.

In the time since the publication of this comment, the issue of direct emitter effects has been largely ignored by hedonics researchers. Yet, it is entirely plausible that many hedonic studies may suffer from this form of omitted variables bias. A coal-fired power plant, for example, will be both a source of airborne particulates and a noisy and unsightly neighbor. Traffic congestion may lead to high ozone levels, but will also produce noise and other negative externalities. Surprisingly few air pollution hedonic studies have explicitly noted this problem. Some researchers have included as an explanatory variable the distance to industrial or manufacturing areas (Harrison and Rubinfeld [13], Jackson [15]), but these studies make no attempt to identify the sources of the specific air pollutant in question nor control for proximity to the specific emitters that may themselves be disamenities.

Only two studies that we have found explicitly mention the possibility that the sources of air pollution may affect property values directly. In a study of the relationship between neighborhood disamenities and housing prices, Li and Brown [18] find that a negative and significant coefficient on air pollution loses significance when neighborhood characteristics such as noise and visual quality are included in their model. They write that

> …since there is a high correlation between air pollution levels and micro-neighborhood characteristics, previous findings about the effect of air pollution may in fact measure closely associated factors such as congestion, noise pollution, and visual disorder.

Likewise, in investigating the effect of particulates on housing values, Diamond [8] writes that there is a "possibility that the presence of high levels of pollution in the more distant suburbs is related to the presence of another disamenity such as a manufacturing area or highway interchange." However, he fails to address this effect with a more complete model specification.

The few water quality hedonics in the literature are likely subject to the same problem. David's [7] early analysis of water quality in Wisconsin lakes explicitly mentions that pulp and paper companies are partly responsible for poor water quality in her sample. However, there is no attempt to test whether the water quality parameter may instead be capturing the odor, air pollution, and noise associated with pulp and paper company operations. Likewise, the negative impact of coliform bacteria on housing prices reported by Brachares [3] could be related to the direct effects of sewage treatment plants and livestock operations; and the positive relationship between water quality and housing prices in rural Pennsylvania described by Epp and Al-Ani [11] may in fact be driven by the direct effect of upstream polluters and undesirable land uses.

The problem of direct emitter effects may seem hopeless. If ambient pollutant levels decline with distance from emitter, then both the level of pollution and the direct emitter disamenity will be hopelessly collinear. Attempting to eliminate the bias by including both the environmental quality measure and the distance to the disamenity will only produce severe multicollinearity. Fortunately, topography, weather, and air and water currents may sometimes serve to break up this collinearity. This is especially true in cases where chemical or biological processes intervene between emissions and observations of environmental quality. Tropospheric ozone, for example, does not form until several hours after its precursors (nitrogen oxides and hydrocarbons) are emitted. Similarly, dissolved oxygen concentrations in water reflect the outcome of relatively slow biological degradation and physical mixing processes. Such delays provide time for air and water currents to disentangle the high correlation between environmental quality and emitter location.

There is a second way in which the potential collinearity between emitter effects and pollution levels can be diffused. If there is a diverse set of emitters and if the strength of the disamenity associated with living near an emitter varies over emitter type, then the independent effect of environmental quality may be identifiable. This is especially true if some of the emitter effects are actually positive rather than negative externalities. A coal-fired power plant and a tilled field both emit particulates, but the neighboring farm might be considered an amenity and the power plant a disamenity.

A Water Quality Hedonic Analysis in Anne Arundel County, MD

Maryland's Anne Arundel County, located on the western shore of the Chesapeake Bay, is especially well suited for a hedonic analysis of water quality. With a highly irregular coastline within 40 miles of both Baltimore and Washington D.C., the number of waterfront properties in the county is substantial. These waterfront locations are valued both for their boat access to the Chesapeake Bay and for *in situ* recreational (swimming, wildlife viewing, fishing and boating) experiences. The irregularity of the coastline (which inhibits mixing), together with the geographic dispersion of sources of water pollution, produces considerable variability in water quality. Monitoring stations distributed along the coast have documented these water quality variations for well over a decade.

Housing and Neighborhood Data

The data set consists of 1,287 sales of waterfront property in Anne Arundel County, Maryland, that occurred between July 1993 and August 1997. Only private, arms-length transactions were considered. The vast majority of the transactions occurred along tidal sections of tributaries to the main stem of the Chesapeake Bay. The data come from the State of Maryland's Tax Assessment data base and are made available from the Maryland Office of Planning which provides geocoded locations for the centroids of every land parcel in the state.[4] Table I lists the variables and their descriptive statistics.

Because the data set contains few structure characteristics and because it is the value of the location that is of most interest to us, we control for the value of housing characteristics by including the assessed value of the structure as an explanatory variable (VALSTRUCT). There are drawbacks to this approach, the most obvious of which is our inability to obtain coefficient estimates for structural characteristics. However, we have little or no interest in the effect of structural characteristics on price and view the additional information available to an on-site assessor as an advantage.

Sales price is also hypothesized to be a function of lot size (ACRES) and commuting distance to nearby cities. Distances were measured using ARC/INFO software along road networks digitized in the Census Bureau's Tiger Line Files. Proximity to Annapolis (DISTANN), the state capital, is expected to be desirable, in part because of employment opportunities, but also because the city offers amenities such as shopping, restaurants, and historic sites. Proximity to Baltimore (DISTBALT), the closest major city and largest employment center in the area, is also expected to be an important determinant of price. Because a larger than normal proportion of waterfront property may be owned by retired individuals or held as second homes, we allow the effect of the distance to Baltimore to vary, depending on the percent of the population in the parcel's Census block group that was employed outside the county (DISTCOMM).

Washington, D.C. is also a major employment center in the region. However, preliminary regressions suggested that distance to Washington did not have a significant effect on property prices, leading us to omit this explanatory variable in the results reported later in the paper. This may have occurred because the Anne Arundel coastline is at the limit of most people's assessment of a reasonable commute (approximately one hour each way); it may also have occurred because there is little variation in commuting distance to Washington over our sample.

In addition to large-scale neighborhood influences such as distances to nearby cities, earlier work on the market for land in this region has repeatedly supported the finding that small-scale neighborhood influences – the pattern of land use surrounding a property – are important as well (Bockstael and Bell [2]; Irwin and Bockstael [14]). Following an approach described in that work, surrounding land use measures are calculated for each parcel as the percent of the land within a three-quarter mile radius that is in each of three categories of land use:[5] (1) dense development (%DENSE -- commercial, manufacturing, and high density residential), (2) open space (%OPEN -- agriculture and natural vegetation), and (3) water (%WATER – open water and wetlands). The percent water measure is included to capture the fact that waterfront properties on peninsulas, with more water accessibility, are likely to be valued more highly. According to our *a priori* expectations, open space should be a positive amenity, but the desirability of dense development is more ambiguous. Dense development may be associated with all the negative externalities of crowding, but it also signals the availability of services such as shopping, schools, hospitals, libraries, etc.

Major dischargers of water pollutants (non-fecal coliform emitters) are also expected to be neighborhood disamenities. Data on these LULU locations within Anne Arundel County were obtained from the EPA,[6] and for each transaction, the inverse distance to the nearest one was calculated (1/DISTPOLL). Two additional variables were included to correct for neighborhood effects - black population as a percent of total population in the Census block group (%BLACK) and percent of owner occupied housing (%OWNOCC).[7] Finally to correct for possible price level changes, given that the sales transactions span a four year period, a time trend is incorporated (YEAR).

Environmental Data

For this analysis we focus on water quality as measured by fecal coliform counts. We choose this measure of water quality because it is one that would conceivably matter to individuals who wish to use the water adjacent to their property for swimming and fishing. Moderate levels of fecal coliform pose a hazard to human health.[8] When levels are extremely high, the water can be unsightly and may give off an unpleasant odor. Just as important for our purposes, a mechanism exists by which water quality information is transmitted to market participants. The County's Department of Health maintains a water quality hotline from Memorial Day to Labor Day that describes weekly sampling results and waterway closings. When waterways are closed to swimmers, signs are posted by county officials. Finally, anecdotal evidence exists that individuals seek information about coliform bacteria levels when buying property.[9]

For several years, the Anne Arundel County Department of Health and the Environment has collected biweekly water samples from 104 stations along the coast of the Chesapeake Bay and analyzed them for fecal coliform bacteria content. The geographic distribution of these monitoring stations is shown in Figure 1. All stations were sampled during the months of April through September. Selected stations were also sampled during the winter months, but these winter observations were eliminated to maintain seasonal consistency across stations.

Each waterfront property was linked to the nearest monitoring station, and the median fecal coliform value for that station in the year of the sale was associated with the property (FECAL). Although the monitoring stations were well distributed along the coast of the county, some inlets and small bays were not monitored; sales transactions for parcels along these sections of coastline were dropped from the data set. The final data set included 1183 transactions. Figure 1 also depicts the location of the centroids of these parcels.

Controlling for Emitter Bias

Because many sources of fecal coliform are undesirable neighbors (independent of the water quality degradation that they cause), we need to convince ourselves that direct emitter effects are not driving our results; we must be sure that factors spatially correlated with water quality are not the true causes of price variation. Fortunately, the sources of fecal coliform in Anne Arundel county's marine environment are quite diverse. This multiplicity of sources is useful in breaking up the potential collinearity between direct emitter effects and fecal coliform levels. If sources differ both in their relative undesirability as neighbors and in their emissions levels, an independent estimate of the effect of water quality may be possible. The varied coastline of the county also aides us in this regard. The irregular coastline leads to diverse flushing and dilution environments, so that significant variations in water quality exist which are independent of distance from the emitters.

Among the potential point sources of fecal coliform, wastewater treatment plants are perhaps the best known. Under normal operating conditions, wastewater treatment plants should not discharge significant quantities of fecal coliform. However, unusually intense rain events or operator mismanagement may lead to unanticipated releases. Potential nonpoint sources of fecal coliform in Anne Arundel County include run-off from commercial animal facilities, boat discharges (direct releases from septic holding tanks), run-off from densely developed areas (e.g. pet wastes), and leaking private septic fields.

The emitter effects associated with point sources are the easiest to control for. In each case, we include a function of the distance to the nearest emitter of its type. Specifically we include these distances in inverse form to allow the effect to dissipate quickly with distance. Thus inverse distance to the nearest wastewater treatment plant (1/DISTSEW) is expect to have a negative coefficient if these plants are undesirable neighbors in their own right. Since data on the location and frequency of nonpoint boat discharges is unobtainable, we treat boat discharges as a point source by including proximity to marina locations as a proxy. As with wastewater treatment plants, the specific explanatory variable is the inverse distance to the nearest marina (1/DISTMAR). We have ambiguous *a priori* expectations for the sign of the coefficient on this variable, since marinas may be considered either desirable or undesirable as neighbors.

The nonpoint sources of fecal coliform are more difficult to capture convincingly, but equally likely to cause emitter effects. Runoff from densely developed areas is considered to be a significant non-point source of fecal coliform in this region, but we argued earlier that the density of development in the surrounding area might have a direct effect on the value of property. The effect may be positive or negative depending on the relative strength of the congestion and accessibility effects. By explicitly including as an explanatory variable the percentage of the land surrounding each parcel that is in dense development (%DENSE), we hope to control for the direct effect of these land uses, whatever the sign. Leaking private septic fields are another potential non-point source of fecal coliform. We account for this emitter effect by including a dummy for public sewer service (PUBSEW) as an explanatory variable. If a house has a private septic system (i.e. it is not connected to a public sewer system), then neighbors are also likely to have private septic systems, and the potential for nonpoint fecal coliform sources will be large. The sign on this variable is difficult to predict, since it is not clear whether a household would view public sewer or septic as preferable. The first involves monthly or quarterly fees, while the latter involves less frequent but potentially large maintenance costs. In addition, the absence of public sewer service will be highly correlated with low-density development areas, which themselves may have an amenity effect. By including a dummy variable for sewer service, we hope to control for all of these potential effects that might be correlated with fecal coliform levels originating from septic fields. A map illustrating the locations or land use patterns associated with most of the known omitters can be found in Figure 2.

Estimation of the Hedonic Price Function

Economic theory can provide little guidance on functional form selection within the hedonic context (Rosen [25]; Palmquist [21]). Cropper, Deck, and McConnell [6] suggest that when variables are omitted or replaced by proxies, simple functional forms are preferred. In preliminary regressions using linear, log-linear, semi-log, and inverse semi-log specifications, we found the sign and significance of most of the variables, including the water quality variable, to be quite stable. Because we will need to treat several econometric issues, we confine our discussion of the results to one commonly used functional form – the semi-log.

We estimated the following semi-log model:

$$\begin{aligned}\ln PRICE = {} & \beta_0 + \beta_1 VALSTRUCT + \beta_2 ACRES + \beta_3 (ACRES * ACRES) + \beta_4 PUBSEW \\ & + \beta_5 DISTBALT + \beta_6 DISTANN + \beta_7 (DISTBALT * DISTANN) \\ & + \beta_8 (DISTBALT * \%COMM) + \beta_9 (DISTMAR)^{-1} + \beta_{10} (DISTSEW)^{-1} \\ & + \beta_{11} (DISTPOLL)^{-1} + \beta_{12} \%DENSE + \beta_{13} \%OPEN + \beta_{14} \%WATER \\ & + \beta_{15} \%BLACK + \beta_{16} OWNOCC + \beta_{17} YEAR + \beta_{18} FECAL + \varepsilon\end{aligned}$$

Ordinary least squares results are reported in the first column of Table II.

Diagnostics checks suggest the presence of heteroscedasticity, not a surprising occurrence in a cross section data set of this sort where property prices vary widely. Plots of OLS residuals against various explanatory variables suggest that the assessed value of the structure may be a good variable to use to normalize the variance. Although the existence of heteroscedasticity will not bias the coefficients, the standard errors will not be correct without treatment of the problem. The second column in Table II reports the results from correcting for heteroscedasticity. The standard errors are now, of course, only asymptotically correct.

A cursory inspection of a plot of the OLS regression residuals on a county map points toward potential problems with spatial dependence in our sample (Figure 3). Furthermore a diagnostic test developed by Kelejian and Robinson [17] fails to reject the null hypothesis of no spatial dependence at a 5% significance level. The consequences of ignoring this spatial dependence are similar to the consequences of ignoring heteroskedasticity: ordinary least squares coefficients will be unbiased, but inefficient, and standard errors will be incorrect. Unfortunately, it is not easy to correct for spatial autocorrelation and heteroscedasticity simultaneously, so we re-estimate the original model correcting for spatial autocorrelation.

In order to take spatial autocorrelation into account, a spatial weights matrix must be specified. The elements of this matrix reflect the strength of the association between any two arbitrarily chosen observations. We choose to use the inverse of the distances between houses as spatial weights. Any parcels separated by more than a mile were assigned a weight of zero. Although this specification seems plausible, the specification of any spatial weights matrix cannot be tested empirically. Parameter estimates from the spatial autocorrelation model are reported in the third column of Table II.

Results and Implications of the Analysis

Our primary interest is in the effect of fecal coliform variation on property values, but reasonable results with respect to other variables will support the validity of the model. The estimated coefficient on the assessed value of the structure is significant and stable over all three models. The estimated coefficient suggests that a $1000 increase in structure value induces approximately a .35% increase in property price. Evaluated at the mean property value of $350,000, the .35% translates into $1225. With respect to lot size, the log of price is increasing at a decreasing rate. Using either the OLS or spatial autocorrelation-corrected estimates and evaluating at a starting point of one acre, an additional one acre increase in lot size (a substantial increase in waterfront property) would cause about a 17% increase in property value. This amounts to about $60,000 on a $350,000 parcel.

As expected, the results from all the models suggest that, *ceteris paribus*, property decreases in value with distance from either of the major cities - Baltimore or Annapolis. Because much of the waterfront property is likely owned by retirees or held as summer homes, we include a variable equal to the distance to Baltimore multiplied by the percent of the population in the Census block group that commutes to work outside the county. This variable gives more weight to Census block groups populated by commuters to Baltimore, which is the major employment center. The coefficient on this variable was significant and negative, increasing the rate of decline in price with distance from Baltimore for parcels in Census block groups with large populations of commuters.

Not surprisingly, an increase in the percent of surrounding area found to be water had a significant, positive, and stable effect on property values over all models. In general however, the effect of the surrounding land use pattern tended to be the least stable feature of the models. In all cases the effect of open space was insignificant. The effect of dense development was positive with varying sized effects in the OLS and heteroscedasticity-corrected models and insignificant in the spatial autocorrelation-corrected model. Expectations about both these variables are complicated by the fact that the marginal effect of more open space or more development may not be constant but may vary with the total amount. Thus, we might expect the value of a marginal change in open space to be much lower in rural than urban areas. The properties included in the analysis span a range of urban, suburban and rural areas.

The estimated coefficients on the trend variable and the percent black in Census block group were significantly different from zero only in the heteroscedasticity-corrected model, but Census block groups with higher percentages of owner occupied houses had, *ceteris paribus*, significantly higher sales prices in all models. The distance to major water pollutant dischargers was found to be a significant determinant of property values. Given the functional form, price increases quite rapidly at first with distance from this locally undesirable land use, but the effect soon levels off. The coefficient associated with public sewer service was unstable over models, but significant only in the heteroscedasticity-corrected model in which it was negative. The coefficients associated with distance to marinas and distance to sewage treatment plants were insignificant at the 95% confidence level.

In all these models and for every other functional form we considered, fecal coliform counts were found to have a significant, negative effect on property values.[10] Using the results from the OLS or spatial autocorrelation-corrected model, a change of one fecal coliform count per mL produced approximately a 1.4% change in property prices or a change of about $5000 for the mean priced property. A one count/mL change is a fairly substantial one, given that the mean of the readings in fecal coliform is about one count/mL and the level at which beaches are closed is about two counts/mL. However, the range in fecal coliform count along this area of the coastline is considerable, from .04/mL to 23/mL.

It would be tempting at this point to use the estimation results to value the benefits to property owners of improvements in water quality along the Anne Arundel coast. One such valuation experiment might involve reducing all fecal coliform counts above a proposed standard to the level of the standard. However, such a change would dramatically affect the supply of this characteristic in the waterfront housing market, making it necessary to presume a subsequent shift in the hedonic price function – one that is impossible to project.

An alternative is to consider a very localized improvement in fecal coliform levels. If only a small number of properties are affected by an improvement, then an approximate measure of the welfare effect of the change can be obtained by using the hedonic function to evaluate the change in the market price of these properties. The change in value of a property is not (necessarily) a measure of the property owner's valuation of the environmental improvement, but a measure of the windfall gain in the value of his asset that he could recover by selling his property to an individual with a higher valuation for the amenity (Palmquist [21], Bartik [1]).

To illustrate the effect of a hypothetical, but reasonable, improvement in fecal coliform counts on a waterfront neighborhood, we considered the Saltworks Creek inlet along the Severn River above Annapolis. Fecal coliform counts in this inlet are considerably elevated over the levels in the Severn River. Counts increase from about .5/mL at the mouth to 1.35/mL about a half mile into the inlet, and finally to a level of about 2.4/mL about a mile from the mouth. We choose a hypothetical level of 1 count per mL as the improved level in the upper reaches of the inlet (at 2 counts/mL the problem is serious enough that the county will consider closing beaches). Using this target level of fecal coliform, we assess the resulting gains in property values from this improvement for the 41 residential parcels that border the upper reaches of this inlet and would presumably be affected. Because we do not have sales prices for all these parcels, we use full market assessed values as reported in the Maryland Tax Assessment data base. The average full market assessed value of these parcels before any change is $262,362, making the sum of full market assessed value for all 41 parcels to be in excess of $10 million. The projected increase in property values due to the hypothetical reduction in fecal coliform averages $2014 per property (an increase of about three-quarters of a percent) or a total of $82,574 for the 41 parcel neighborhood.

Of course this property value change could not be extrapolated to the entire county because the hedonic price function would likely shift as a result of the supply effect of having more of the "clean water" characteristic on the market. Such an extrapolation would overestimate the welfare effect of a reduction in fecal coliform. However there are a large number of waterfront properties in Anne Arundel County, so our finding of a significant price effect and a substantial per property benefit suggests a potentially large welfare gain from water quality improvements.[11]

Conclusions

The paucity of hedonic water quality studies is startling, particularly in light of the widespread application of hedonic techniques to air pollution. Most studies employ observations on water clarity, a proxy for water quality with ambiguous ecological merit.[12] Furthermore, none of these studies pay particular attention to the potential for omitted variable bias. This paper takes advantage of a unique geographical environment – a lively housing market along an estuary with large variations in water quality – to show that improved water quality has a positive and significant effect on property values.

As with all empirical economics, a convincing story must lie behind the econometrics. Perhaps the most difficult problem in trying to use behavioral models to value environmental policy changes is establishing with some degree of confidence the link between an objectively measurable environmental change and the behavior of individuals. Even a statistically significant relationship between behavior and an environmental measure does not demonstrate causation. Hedonic studies of environmental quality are particularly vulnerable to omitted variables bias: the emitters of pollution are often unpleasant neighbors for reasons completely unrelated to air or water quality. Very few hedonic studies have addressed – or even mentioned – this effect. We control for it by including a number of measures of the direct effect of the emitters. Having accounted for emitted variables bias as well as we can, we conclude with some confidence that waterfront homeowners have a positive willingness to pay for reductions in fecal coliform bacteria concentrations as demonstrated in the property prices that reflect their bids for property attributes. The fact that the U.S. EPA is currently considering national standards for fecal coliform makes this result of special significance.

References

1. T. Bartik, Measuring the benefits of amenity improvements in hedonic price models, *Land Econom.* **64**, 172-183 (1988).
2. N. E. Bockstael and K. Bell, Land use patterns and water quality: the effect of differential land management controls, *in* "International Water and Resource Economics Consortium, Conflict and Cooperation on Trans-Boundary Water Resources" (R. Just and S. Netanyahu, Ed.), Kluwer Publishing (1997).
3. E. Brashares, "Estimating the instream value of lake water quality in Southeast Michigan," unpublished Ph.D. dissertation, University of Michigan, 1985.
4. E. Cassel and R. Mendelsohn, The choice of functional forms for hedonic price equations: comment, *Journal of Urban Econom*. **18**, 135-142 (1985).
5. D. Clark and L. Nieves, An interregional hedonic analysis of noxious facility impacts on local wages and property values, *J. of Environ. Econom. and Management.* **27**, 235-253 (1994).
6. M.L. Cropper, L.B. Deck, and K. E. McConnell, On the choice of functional form for hedonic price functions, *Rev. of Econom. Statist.* **70**, 668-675 (1988).
7. E. L. David, Lakeshore property values: a guide to public investment in recreation, *Water Resources Research*, **4**, 697-707 (1968).
8. D.B. Diamond, The relationship between amenities and urban land prices, *Land Economics*. **56,** 21-32 (1980).
9. J. H. Dorfman, A. G. Keeler, and W. Kiesel, Valuing risk – reducing interventions with hedonic models: the case of erosion protection, *J. Agric. Res. Econom.* **21**, 109-119 (1996).
10. J. Englin, Estimating the amenity value of rainfall, *Annals Reg. Science.* **30**, 273-283 (1996).
11. D. Epp and K.S. Al-Ani, The effect of water quality on rural nonfarm residential property values, *Amer. J. Agric. Econom*. **61**, 529-534 (1979).
12. D. Feenberg and E.Mills, *Measuring the benefits of water pollution abatement*. Academic Press, New York (1980).
13. D. Harrison and D. L. Rubinfeld, The air pollution and property value debate: some empirical evidence, *Rev. of Econom. and Statist*. **6**, 635-638 (1978).
14. E. Irwin and N. E. Bockstael, Economic theories of land use patterns: how well do they explain current patterns of exurban sprawl?" working paper, Department of Agricultural and Resource Economics, University of Maryland, (1997).
15. J.R. Jackson, Intraurban variation in the price of housing, *J. Urban Econom.* **6**, 464-479 (1979).
16. H. Kelejian and I.R. Prucha, A generalized moments estimator for the autoregressive parameter in a spatial model, *International Economic Review*, forthcoming, (1998).
17. H. Kelejian and D. Robinson, Spatial autocorrelation: a new computaionally simple test with an application to per capita county police expenditures, *Reg. Science Urban Econom.* **22**, 317-331 (1992).
18. M. Li and J.H. Brown, Micro-neighborhood externalities and hedonic housing prices, *Land Economics* **56**, 125-140 (1980).
19. H. Michael, K. Boyle, and R. Bouchard, Does the measurement of environmental quality affect implicit prices estimated from hedonic models, Triangle Economic Research, manuscript, (1997).
20. R. G. Michaels and V. K. Smith, Market segmentation and valuing amenities with hedonic models: the case of hazardous waste sites, *J. Urban Econom*. **28**, 223-42 (1990).

21. R.B. Palmquist, Hedonic Methods, *in* "Environmental Benefit Measurement" (J. Braden and C. Kolstad, Ed.), North-Holland, Amsterdam (1991).
22. R.B. Palmquist, Valuing localized externalities, *J. Urban Econom*. **31**, 59-68 (1992).
23. R.B. Palmquist, R. and L. Danielson, A hedonic study of the effects of erosion control and drainage on farmland values, *Amer. J. of Agric. Econom.* **71**, 55-62 (1989).
24. R.B. Palmquist, F. Roka, and T. Vukina, Hog operations, environmental effects, and residential property values, *Land Econom.* **73**, 114-124 (1997).
25. S. Rosen, Hedonic prices and implicit markets: product differentiation in pure competition, *J. of Pol. Econom.* **82**, 34-55 (1974).
26. T. Schelling, "Micromotives and Macrobehavior," W. W. Norton, New York (1978).
27. K.A. Small, Air pollution and property values: further comment, *Rev. of Econom. and Statist.* **57**, 105-107 (1974).
28. V.K. Smith and J-C. Huang, Hedonic models and air pollution: twenty-five years and counting, *Environ. Res. Econom.* **3**, 381-394 (1993).
29. V.K. Smith and J-C. Huang, Can markets value air quality? a meta-analysis of hedonic property value models, *J.Pol. Econom*. **103**, 209-227 (1995).
30. V.K. Smith and W. Desvousges, The value of avoiding a LULU: hazardous waste disposal sites, *Rev. Econom. Statist*. **78(2)**, 293-299 (1986).
31. D. Steinnes, Measuring the economic value of water quality, *Annals of Reg. Science* **26**, 171-176 (1992).
32. F.V. Waugh, Quality factors influencing vegetable prices, *J. of Farm Econom.* **10**, 185-196 (1928).

TABLE I

Variables and Descriptive Statistics

Variable	Description	Units	Min	Max	Mean	Std. Dev.
PRICE	Market price	$	25,000	2,000,000	349,523	248,027
VALSTRUCT	Assessed value of structure	$	1,000	1,081,915	118,283	97,378
ACRES	Lot size	acres	0.05	14.25	0.68	1.06
PUBSEW	=1 if residence served by public water and sewer	-	0	1	0.48	0.50
DISTBALT	Distance to Baltimore	miles	8.66	51.88	26.82	8.28
DISTANN	Distance to Annapolis	miles	0.31	28.98	12.27	7.04
DISTMAR	Distance to nearest marina with at least 20 boat slips	miles	0.00	3.04	0.83	0.67
DISTSEW	Distance to nearest sewage treatment plant	miles	0.14	7.53	3.10	1.73
DISTPOLL	Distance to nearest major discharger of water pollutants	miles	0.54	27.16	11.13	6.04
%COMM	% of residents in census block group who commute out of county	-	0.08	0.55	0.29	0.10
%BLACK	% of residents in census block group who are black	-	0.00	0.69	0.07	0.13
%OWNOCC	% of residences in census block group that are owner occupied	-	0.00	1.00	0.86	0.35
%DENSE	Percentage of land within 3/4 mile that is densely developed	-	0.00	0.34	0.04	0.07
%OPEN	Percentage of land within 3/4 mile that is open space	-	0.00	0.73	0.23	0.15
%WATER	Percentage of land within 3/4 mile that is water/wetlands	-	0.04	0.79	0.34	0.18
YEAR	Year of sale	years	93	97	94.99	1.28
FECAL	Median fecal coliform concentration at nearest monitoring station in year of sale	count/mL	0.04	23.00	1.03	1.82

TABLE II
Parameter Estimates

Variable	OLS	Heteroskedastic Error	Spatial Model
Intercept	11.8107	10.2303	11.7946
	(0.7520)	(0.6659)	(0.7317)
Value of structure (in 1000s)	0.0034	0.0037	0.0033
	(0.0001)	(0.0001)	(0.0001)
Lot size	0.2038	0.1065	0.2155
	(0.0226)	(0.0200)	(0.0226)
Lot size X lot size	-0.0150	-0.0052	-0.0157
	(0.0024)	(0.0025)	(0.0024)
Public sewer service	-0.0190	-0.0552	0.0080
	-0.0247	(0.0222)	-0.0288
Distance to Baltimore	-0.0137	-0.0155	-0.0115
	(0.0046)	(0.0041)	(0.0072)
Distance to Annapolis	-0.0383	-0.0344	-0.0333
	(0.0070)	(0.0063)	(0.0107)
Dist. Balt. X dist. Annap.	0.0010	0.0009	0.0007
	(0.0003)	(0.0002)	(0.0004)
Dist. Balt. X %commuters	-0.0321	-0.0285	-0.0231
	(0.0056)	(0.0052)	(0.0071)
Inv(dist. marina)	0.0009	0.0008	0.0003
	(0.0006)	(0.0006)	(0.0006)
Inv(dist. sewage treatment)	-0.0119	0.0287	-0.0189
	(0.0240)	(0.0198)	(0.0304)
Inv(dist. water polluter)	-0.4949	-0.5334	-0.4063
	(0.0793)	(0.0754)	(0.1029)
%densely developed	0.3123	0.1871	0.1753
	(0.1122)	(0.0986)	(0.1582)
%open space	0.0669	-0.0558	0.0317
	(0.0610)	(0.0464)	(0.0734)
%water or wetlands	0.3166	0.2257	0.2894
	(0.0508)	(0.0451)	(0.0656)
%black	0.0445	0.1807	0.1514
	(0.0949)	(0.0797)	(0.1322)
%owner occupied	0.0863	0.1093	0.0928
	(0.0288)	(0.0270)	(0.0277)
Year	0.0083	0.0259	0.0076
	(0.0078)	(0.0069)	(0.0075)
Fecal coliform	-0.0149	-0.0201	-0.0137
	(0.0059)	(0.0057)	(0.0065)
N	1183	1183	1183
R-squared	0.6957	0.7154	0.6570

Notes: Dependent variable is natural log of price. Standard errors in parentheses.

ENDNOTES

[1] Identification in the context of multiple markets is possible in concept, but few multi-market analyses have been published. The necessary conditions for identification are so stringent as to make suitable applications difficult to find.

[2] Other environmentally related goods that have been treated in a hedonic framework include odor (Palmquist, Roka, and Vukina [24]), soil erosion (Dorfman, Keeler and Kiesel [9]; Palmquist and Danielson [23]), risks from hazardous waste sites (Michaels and Smith [20], Smith and Desvousges [30]), rainfall (Englin [10], and noxious facilities (Clark and Nieves 1994 [5]).

[3] Some dimensions of water quality are very difficult or impossible for market participants to observe. For example, ecologists might be concerned with dissolved oxygen, pH, or nitrate concentration, all of which are essentially invisible to the casual observer.

[4] Beginning in 1996, the MOP began producing Maryland Property View, a GIS product which maps the centroids of all parcels in the tax assessment data base. We matched the sales parcels to this geocoded data base.

[5] Land use data was obtained from the Maryland Office of Planning's digitized land use maps for 1990.

[6] Data were obtained from the U.S. EPA's website, www.epa.gov. Water discharge sites included in DISTPOLL are "major" National Pollution Discharge Elimination System (NPDES) facilities. "Major" is defined by EPA as "facilities which discharge more than one million gallons per day, or are considered to have a significant environmental impact on the area."

[7] Inclusion of socio-demographic characteristics of neighborhoods is common in hedonic studies, but for reasons not often well articulated. Following Schelling's argument [26], certain groups may prefer to live in neighborhoods with similar socio-demographic characteristics. If these groups are also the wealthier individuals, they will bid up prices in these more "exclusive" neighborhoods.

[8] The State of Maryland recommends that beaches be closed if a logarithmic mean of 2 fecal coliform counts per ml water is exceeded over a 30-day period. The Environmental Protection Agency is in the process of developing national standards for fecal coliform.

[9] Department of Health officials estimate that they receive several calls each month from realtors interested in water quality at particular locations.

[10] This result does not change when the assumption of normal errors is relaxed: an analysis using the generalized method of moments technique (Kelejian and Prucha [16]) while correcting for spatial autocorrelation indicated that fecal coliform is still highly significant.

[11] There will of course be others who benefit from improvements in water quality – those without water frontage but with water access and recreationists visiting public access points. So an accurate measure of the benefits to property owners would still only be a lower bound on the benefits of clean-up.

[12] While eutrophication leads to anoxic conditions and low water clarity, many lakes in the northern Adirondaks are crystal clear, yet sterile and acidic.