Choice margins and ecosystem services: The case of an urban watershed[±]

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Revision Date: July 5, 2005

[±] Funding provided by the US EPA STAR grant program through grant number # R-82950801 to the authors.

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Abstract:

We examine values held by homeowners in Wake County, North Carolina for the environmental services of an urban watershed. We use the distinction between long and short run choices to integrate a hedonic property value model with a recreation demand model for short trips to local water recreation sites. Using spatially integrated data and models on home sales, recreation trips, and water quality we find that proximity to waterfronts, access to recreation sites, and water quality for recreation positively influence home values. We use our estimates in combination with a predictive water quality model to assess the changes in welfare resulting from growth-induced changes in water quality in the county. We find marked differences in the scale and spatial distribution of welfare effects for predicted growth scenarios.

1. Introduction

One of the more important challenges facing environmental policy analysts today stems from the need to measure the gains or losses resulting from changes in ecological resource services. In this paper we consider one aspect of this challenge: the task of measuring the welfare impacts of changes in water quality in a rapidly growing urban watershed. In many areas of the country increasing demand for residential housing and the subsequent development of supporting retail services have taxed the ability of watersheds to provide basic environmental services. At the same time, much of the growth in housing demand can be broadly viewed as amenity driven. There is a fundamental tradeoff to be faced between the largely private benefits from increased development and the public costs of amenity consequences from development-related land cover changes. Designing effective government policy to address this tradeoff requires information of several types. Land use regulations, controls on point and non-point sources of pollution, and open space initiatives can all improve urban water quality and enhance complementary watershed services such as recreation opportunities and landscape amenities. The types, magnitudes, and spatial distribution of the costs and benefits from these policy options can vary substantially, however. Techniques for mapping policy interventions to environmental improvements to net economic benefits are necessary for distinguishing among competing regulatory options. Our focus here is on the specific challenges involved with measuring the economic benefits from changes in urban water quality.

Measuring the economic benefit of a change in urban watershed quality is made difficult by the complex ways in which residents interact with and are served by the watershed. A partial list of services potentially related to watershed health includes recreation opportunities, residential amenities, wildlife populations, drinking water, wastewater processing, and storm water filtration and storage. The production technology for these services is almost certainly non-separable, which is to say that a change in general watershed health (for example through wetlands restoration, buffer strip requirements, or clearing for a new sub-division) can impact individuals through the multiple pathways of the portfolio of services. The operational challenges for non-market valuation implied by this are substantial. To fully value a change in water quality we must define the set of watershed services consumed by individuals, link measures of watershed health to service quantity or quality, and estimate a utility function defined over the set of services.

It is fair to say that no exercise in watershed valuation (urban or otherwise) has approached this ideal. Non-market valuation techniques by design tend to focus on a single point of interaction between behavior and the environment. This is particularly true of revealed preference methods. For example, the recreational benefits of water quality can be calculated by linking travel demand to spatially varying levels of water quality. Likewise property value models can be used to value landscape amenities. These models have proven successful because they focus narrowly on a single well-defined decision point that can be related to specific and spatially precise indicators of environmental quality. The use of a single choice margin allows recovery of only one component of preferences when in fact multiple components may be relevant.

In this paper we focus on estimating the non-market value of an urban watershed by combining recreation and property value data in a single model of preferences. We apply a technique proposed in related work (see Phaneuf, Smith, and Palmquist, 2005) to data from Wake County, North Carolina to gauge how recreation access, water quality, and the amenity affects of proximity to lakes are capitalized into housing prices. In particular, we use data on recreation trips to local water resources in the county to construct a spatially varying, quality adjusted 'price index' for recreation access. This price index and a distance-based amenity proxy are then included in a hedonic property value model to measure how the two watershed services are reflected in property values. By using the two choice margins we are able to isolate and separately measure the amenity and recreation access effects of water resources in the county. Similar to other studies we find that proximity to lakes increases home values. Unique to this study, however, we also find that surrounding water quality simultaneously contributes to home values through its affect on the quality of recreation services.

The remainder of the paper is organized as follows. Section 2 provides an overview of Wake County, NC and our motivation for studying this area. Section 3 reviews literature related to property values and water resources. Section 4 describes the conceptual basis for our approach, and section 5 describes the data. Section 6 describes our estimation approach and results, and Section 7 concludes.

2. Study Area

Our application site is Wake County, North Carolina, shown in figure 1a. Eighty-five percent of Wake County lies in the Neuse river basin, with the remainder in the Cape Fear basin. It is the home to the state capital, Raleigh, and is one of three counties surrounding the Research Triangle Park (RTP), a nationally recognized zone for research oriented public and private facilities. The RTP has been a major stimulus for employment growth in the region. Overall, North Carolina has a rapidly changing landscape. It was ranked fifth in land area developed during the middle 1990's according to statistics from the Center on Urban and

Metropolitan Growth, and that pattern seems to have accelerated in the area around RTP. For example, Wake County currently has the second largest population in the state. Population grew by 48% between 1990 and 2000 and added another 15% between 2000 and 2004. This growth generates new housing units (4,208 building permits were issued in 1990, compare with 13,779 in 2000), an increased proportion of land in impervious surface, and growing threats to the quality of watersheds in the county. Recognizing this prospect, the county commissioned a comprehensive watershed management plan in November 2000 (see CH2MHill, 2003). The CH2MHill analysis defined 80 sub-hydrological zones based on the county's hydrology. Figure 1b displays the spatial definitions in relation to the county boundaries. Only 30 of the 80 sub-hydrological zones were judged to be 'healthy' based on the available biological and chemical data on each area.

There are twelve municipalities in the county. Figure 1c shows their land area and location in relation to major water bodies in the region. A key consideration in developing an economic description of the role of watershed amenities in household location choices concerns the relationship between the spatial unit of measurement for watershed characteristics and the economic decisions included in the analysis. In our case, the two economic choices involve the selection of a home and decisions about local recreation outings close to these homes sites. For the former, neighborhood attributes must be integrated into the description of these choices so that the spatial locations identified by map coordinates for each house have economically relevant context. Distances to employment centers, shopping, schools, etc. are part of this characterization. More difficult aspects of the characterization relate to neighborhood attributes less easily defined by such distance measures. Sometimes labeled housing sub-markets, these may be characterizations of the ethnic or demographic groups present in areas, heterogeneity in housing prices or characteristics (e.g. developed older neighborhoods versus new sub-divisions), or density of development. To capture the influence of these factors we used the Board of Realtors' Multiple Listing Service (MLS) definitions for submarkets. These 18 sub-areas are given figure 1d. The MSL definitions were used in the design of our sampling plan and in the definition of our quality adjusted index of recreation accessibility (see below).

An important issue in implementing our models arises in establishing a concordance between the various spatial definitions represented by the hydrological zones whose water quality and watershed attributes are measured, the housing sub-markets, the physical locations of water bodies and related recreation sites, and the municipalities in the county. All features presumably interact to influence location choices. A comparison of the four panels in figure 1 shows that they do not "nest" naturally within each other. As a result, implementation choices will influence the interpretation given to estimates of the influence of amenities assumed to be associated with housing locations versus those attributed to recreation sites.

3. Related Literature

Environmental property value studies have considered a large breadth of environmental problems, and there is substantial depth in applications considering common problems such as air pollution and hazardous wastes. Yet there have very few hedonic studies of water pollution, one of the most common pollution problems. This is because water and water quality affect properties in a variety of ways, and it has been difficult to capture many of these effects. Water quality can have a direct amenity effect on properties, but only for properties that are directly adjacent to the water body. Nearly all existing hedonic studies have excluded non-waterfront properties and considered only the direct amenity effects. However, it is usually difficult to find enough waterfront properties and enough variation in water quality to conduct such a study. The effects of water quality on non-waterfront properties generally have not been studied. Yet nearby water bodies can affect properties that are not immediately adjacent in a wide variety of ways, including availability for uses such as swimming, fishing, and taking walks. Water quality can affect these local recreation opportunities, and this in turn can affect property values.

While the existing literature has not addressed measuring this effect, there are two strands in the literature that are related to the current study. The first strand is the handful of studies on the effect of water quality on waterfront property values.[1] The earliest study of this type was done by Elizabeth David (1968) for waterfront properties in Wisconsin. At that time property value studies were beginning to be widely used by environmental economists. David used three categories of water quality based on the opinions of government officials. For their study of Pennsylvania streams, Epp and Al-Ani (1979) used an objective measure, a dummy variable for pH below 5.5, and a subjective measure, a dummy variable for the perceived water quality problems. More recently Leggett and Bockstael (2000) used a measure of fecal coliform in their carefully designed study of the coastal properties on the Chesapeake Bay. Finally, waterfront properties on Maine lakes were studied in Michael et al. (2000) and Poor et al. (2001). The latter study used an objective measure, clarity measured by Secchi disk, and a subjective measure, perceived clarity from a survey. Interestingly, the objective measure performed better.

The only published study that used properties that were not adjacent to the water appears to be Mendelsohn, et al. (1992). This study arose out of the natural resource damage case over PCBs in and around the New Bedford, Massachusetts harbor. They divided properties into several zones depending on the PCB levels in the nearest water. While they used properties up to two miles from the water, they did not consider the effect of the distance from the harbor. This study used repeat sales before and after the presence of PCBs was publicized rather than a hedonic study.

The other strand in the literature that is relevant to this paper concerns the relationship between property value models and recreation demand models. The New Bedford case also motivated consideration of this important issue. In researching the case for the plaintiffs, some economists focused on recreation and some on property values. McConnell (1990) raised questions about the possibility of double counting. McConnell develops a model of a lake that is used for recreation and serves the homeowners in the vicinity of the lake. Abstracting from the empirical complexities, he concentrates on the theoretical implementation of both a two-stage hedonic model and a travel cost model. If the lake only has value for recreation, the two models yield identical results. If the lake also has amenity value for the properties, the hedonic model captures all benefits and the travel cost model captures only part. Adding pollution to the model yields similar results. Given that the model points to clear advantages in using hedonic methods to evaluate water-based recreation benefits to homeowners, it may seem surprising that it has not led to applications. However, it does abstract from many of the issues faced in actual implementation. One of these is that there are typically a number of recreation opportunities provided by a residential location. Yet it is difficult to include each of those opportunities separately in a hedonic equation. The methodology in this paper addresses that problem.

Parsons (1991) also raised the problem that recreation and residential location decisions may be intertwined. If residential decisions are partially based on recreation opportunities, then the price variable in a travel cost model will be endogenous. Parsons proposes several types of potential instruments that could be used in a travel cost model to solve the endogeneity problem. His empirical experiment with a simple travel cost model suggests that the bias due to the endogeneity may not be trivial. Similarly, Randall (1994) discusses various potential problems with the price variable used in travel cost models, including the difficulty sorting out the recreation and residential location decisions. The alternative implemented here incorporates information from a recreation model into a property value model to approach this problem in a different way.

4. Method

The types of recreation that have received the most attention in the literature probably have little influence on residential location choices. Most studies have considered full day or multiple day trips, with non-trivial travel costs getting to the sites. The difference in travel time between living on one side of a city or the other is small relative to the time spent getting from the city to the sites. Residential location choices may be influenced by job and school locations and by amenities around the house, but not by distant recreation sites. However, this paper focuses on local recreation. Local recreation involves short trips to the recreation sites with short on-site stays. The time-cost of accessing these local sites can vary substantially within an urban area. In this case the local recreation opportunities may influence residential location choice, and these choices will be reflected in the housing values in different parts of the city. The purpose of this paper is to develop and implement a methodology for incorporating the diverse recreation opportunities into a hedonic model. To accomplish this we use the 'choice margin' approach described in Phaneuf, Smith, and Palmquist (2005).

We define a choice margin as a resource allocation decision made by an individual or household that leads to the acquisition of both a private good and the services of a non-market good. In this paper we distinguish long run choices that involve the selection of a neighborhood and the purchase of housing, and short run choices involving trips to local recreation sites for short outings. The short run choices are made conditional on the long run location decision. Once the location choice is made a household allocates remaining time and money resources to purchased goods, leisure, and recreation. Since the location choice influences the choice set for short-run decisions it seems reasonable to expect that when deciding on a residential location the household considers the portfolio of amenities conveyed by the location, the accessibility of areas for recreation, and how these (or other) amenities relate to the quality of recreation opportunities. These factors will contribute to the expected future gains from recreation trips originating from the location.

To model these decisions we consider a two stage choice process. Household preferences are a function of recreation trips to local sites $x(q)$, a numeraire good z, and housing services $h(a,q)$ where a is a vector of housing attributes and q is a measure of environmental quality. Denote the household's preference function by

$$U = U\left(x\left(q\right), h\left(a,q\right), z, \varepsilon\right), \qquad (1)$$

where ε is an error term denoting household heterogeneity that is unobserved by the analyst. In considering the short run decisions over $x(q)$ and z we assume $h(a,q)$ is quasi-fixed. If m^*

is the household's annual income and $p_h(a,q)$ is the annual cost of a unit of housing the short run decision is

$$\max_{x,z} U\left(x(q), z \mid h(a,q)\right) \quad s.t. \quad m = p_x x(q) + z, \tag{2}$$

where $m = m^* - p_h(a,q)$ is income net of housing costs. The first order conditions for this problem imply solutions for the recreation demand and market goods conditional on the housing choice. Denote the conditional indirect utility function for the short run problem by $V=V(p_x,m,q,\varepsilon)$.

Recreation demand models use an estimate of V to compute the realized ex post benefits to a household or individual from visits to the recreation sites. Employing Roy's Identity the annual consumer surplus from recreation is

$$CS\left(q,\varepsilon\right) = \int_{p_x}^{p_x^c} -\frac{V_{p_x}(\cdot,q,\varepsilon)}{V_m(\cdot,q,\varepsilon)}\, dp_x, \tag{3}$$

where p_x^c denotes the choke price for visits to the recreation site. In addition, if restrictions on how income enters the demand for trips are maintained the change in annual consumer surplus from recreation due to a change in q is

$$\Delta CS\left(q_0,q_1,\varepsilon\right) = \int_{p_x(q_1)}^{p_x^c(q_1)} -\frac{V_{p_x}(\cdot,q_1,\varepsilon)}{V_m(\cdot,q_1,\varepsilon)}\, dp_x - \int_{p_x(q_0)}^{p_x^c(q_0)} -\frac{V_{p_x}(\cdot,q_0,\varepsilon)}{V_m(\cdot,q_0,\varepsilon)}\, dp_x, \tag{4}$$

where q_0 and q_1 denote the original and new values for q, respectively. Recreation models use a single choice margin (observations on trip taking) and equations (3) and (4) to compute a component of the value from an ecological service q.

To see how additional choice margins can be incorporated into the analysis consider how the value of trips at a given quality level might influence other decisions. Equation (3) provides a summary of the gains due to the household's ability to take trips to the recreation site. It is the ex post benefit from the access conditions giving rise to recreation trips at a given quality level. In making a residential choice, it seems reasonable to suppose that households consider, ex ante, the expectation of what these benefits would be for each possible neighborhood. In other words, households consider the value of the recreation options implied by the choice of each neighborhood. If recreation opportunities and/or environmental quality vary spatially, each area provides somewhat different access conditions for recreation. As a result, we argue that the expected recreation benefits available from a residential location can be seen as an attribute of the location. In our model we define the expected benefits from recreation at a given residential location by

$$ECS(q) = E\left[CS(q,\varepsilon)\right], \tag{5}$$

where the expectation operator is with respect to the heterogeneity across households in the location, both observed and unobserved. Equation (5) is not a household specific measure. Rather, it is a measure of the average recreation benefits available because a household has the access defined by one location compared to no access. Of course, in practice the choice is based on each neighborhood's relative value, so the default of no access becomes irrelevant. The expectation is across diverse households conditional on the level of q at each specific location. Using a long run perspective, we hypothesize that this value would be capitalized into housing prices in equilibrium.

The long run component of our model considers the housing choice. As part of this choice we assume that households evaluate how different spatial locations convey different potential benefits for local recreation outings. Since recreation decisions are made in the future conditional on the location choice we replace $x(q)$ in the preference function with $ECS(q)$ when evaluating the housing choice stage. This implies a sub-optimization takes place for each value of q during which the household considers the future potential recreational benefits of the location, and conditions its location choice on this value. More formally the objective function in the long run is

$$U = U\left(ECS(q), h\left(a, q\right), z, \varepsilon\right), \tag{6}$$

and the relevant budget constraint is

$$m^* = p_h(a, q) + p_x \tilde{x} + z, \tag{7}$$

where $\tilde{x}$ is the optimized value of x given q.

With the actual values of x and z selected in a subsequent decision the optimal value of $h(a,q)$ is determined by the spatial choice of a and q holding $ECS(q)$ constant for a location. The first order conditions in this case show that, in choosing a location, the household balances the benefits of a higher level of q with the marginal increase in housing cost:

$$\frac{\frac{\partial u}{\partial ECS} \cdot \frac{\partial EMCS}{\partial q} + \frac{\partial u}{\partial h} \cdot \frac{\partial h}{\partial q}}{\frac{\partial u}{\partial z}} = \frac{\partial p_h}{\partial q}. \tag{8}$$

At the margin, households choose a residential location such that the marginal value of expected recreation plus aesthetic benefits of the location are balanced against the implicit marginal purchase price of the amenities. Equation (8) implies that the elements of q can influence home prices both directly through the amenity effect and indirectly through the recreation effect.

To operationalize this logic, suppose an urban watershed can be divided into J areas corresponding to well-defined real estate markets. The total number of recreation sites in the watershed is K, and the quality associated with a given site k is q_k. The spatial layout of the landscape and existing amenity levels convey a similar portfolio of access to recreation opportunities for each resident in a market area *j*. Given observations on visits to sites by residents of the watershed it is possible to estimate a random utility model of site choice. Denote the indirect utility for a visit by person *i* to site *k* by

$$V_{ik} = \alpha + \beta t_{ik} + \delta q_k + \varepsilon_{ik}, \quad i = 1,..., N, \quad k = 1,...K, \tag{9}$$

where t_{ik} is a measure of the time cost for visiting site *k*, (α,β,δ) are parameters to be estimated, and ε_{ik} is a random error term distributed type I extreme value. With this distribution for the error term estimation of the site choice model in (9) is straightforward, and the expected utility per trip for a person in the sample is

$$EV_i = \ln\left[\sum_{k=1}^{K} \exp(\hat{V}_{ik})\right], \tag{10}$$

where $\hat{V}_{ik}$ is the predicted deterministic component of utility for person *i*.

The expected utility available to a person from the *K* recreation sites varies across the watershed due to spatial variability in the time needed to access sites with spatially varying quality. Closer proximity to sites of higher quality will on average convey a higher per trip utility level, and may be capitalized into home prices. Equation (10) is an individual-specific reflection of the expected utility available from the portfolio of sites and their attributes, and is therefore not an appropriate index for measuring location-specific recreation benefits. Define instead the expected utility from recreation for residents of market *j* as

$$EV^j = N_j^{-1} \sum_{i=1}^{N_j} \ln\left[\sum_{k=1}^{K} \exp(\hat{V}_{ik})\right], \tag{11}$$

where N_j is the number of person-trips originating from market area *j*. By averaging out all observed and unobserved household heterogeneity, equation (11) provides a location specific and spatially varying single dimension “quality adjusted quantity index” for the recreation opportunities conveyed by a given neighborhood.

By appropriately pricing the shadow value of time it is possible to use the model developed above to assess the ex post benefits of improvements in recreation site quality levels. Our primary purpose, however, is to use the quality index in conjunction with a hedonic model to measure how recreation opportunities are reflected ex ante in housing prices. Define the hedonic price equation for home sales occurring in the watershed by the semi-log form[2]

$$\ln p = \alpha_0 + \sum_{l=1}^{s} \beta_l a + \gamma_1 EV^j + \gamma_2 q\left(d\right) + u, \tag{12}$$

where $q(d)$ describes the neighborhood amenity effect of a resource q. Estimation of equation (12) allows separate identification of the direct and indirect effects of amenities on housing prices. Although the first stage hedonic does not allow calculation of exact welfare measures, it is possible to bound willingness to pay measures for changes in watershed quality. For the semi-log form the welfare bound for property i for a change in the recreation index due to a change in q is

$$B = \theta \times \gamma_1 \times p_i \times \left[EV^j(q_1) - EV^j(q_0) \right], \tag{13}$$

where θ an annualization factor.

5. Data

Our approach requires spatially explicit data on home sales, recreation decisions by homeowners, and water quality for Wake County, North Carolina. As part of a larger project examining water quality in the county and state we constructed a database that integrates property sales data obtained from the Wake County Revenue Department, survey data obtained from a sample of homeowners in the county, and water quality monitoring station data from a variety of state, municipal, and private sources. Records for approximately 100,000 private home sales occurring between 1992 and 2000 are contained in our database. Table 1A in the appendix provides a description of a subset of the structural and neighborhood variables coded for each property in the data. The level of resolution in structural and other attributes is more complete than in almost any hedonic dataset. Fulcher (2003) and Palmquist and Fulcher (2004) provide a thorough description and analysis of these data, suggesting specifications for the structural and neighborhood variables that we employ here as well. In this paper we use sales from 1998 and 1999, totaling more than 38,000 observations. The mean prices for sales during these years are $177,686 and $183,208, respectively. Homes have on average 1988 square feet of heated living space, 2.5 bathrooms, are 11 years old, and sit on 0.45 acre lots.

The behavioral component of our database was obtained through a mail survey sent to Wake County homeowners between May 2003 and September 2003. Our objective was to gather household specific information for a proportion of the homes represented in our sales data, allowing us to link location decisions to other household activities, including recreation. Using the Wake County home sales records we selected a subset of owner-occupied properties for our sample. Properties were randomly selected subject to four filters. First, we excluded properties that sold for less than $50,000. Second, the county was divided into four quadrants based on an aggregation of the MLS zones described above. Nine thousand properties were drawn such that they were evenly distributed across the four aggregate real estate zones. Third, we included checks to assure that the hydrological division of the county was also reasonably well represented by the sales data. The sampled properties were evaluated to assure a sufficient number of observations fell in each of the CH2MHill sub-hydrologic units. For each sub-hydrologic area we determined if the initial draw of 9000 properties resulted in at least twenty observations from the area. For the areas that did not meet this criteria we randomly selected additional observations to raise the number in each hydrological area to twenty. For areas with an insufficient number of sales we simply selected all that met our criteria. Finally, property owners' names and addresses were verified using the current Wake County property tax records. Only properties for which the sales record from our hedonic database could be cross-linked to the currently listed owner were included in the final sample. This resulted in 7554 matched names and addresses, each of whom was sent a mail survey following the Dillman (1978) protocol. We had a 32% response rate that provided slightly more than two thousand completed surveys.[3]

Our survey collected a wide range of information on homeowners' socio-economic characteristics, residential location choice, water recreation behavior, and leisure time choices. We collected two types of recreation data based on feedback from two focus groups: (a) information on state-wide visits to lakes, streams and coastal areas; and (b) information on 'local outings'. We define local outings as short excursions to sites close to home involving at most a few hours of combined on-site and travel time. To our knowledge trip-taking behavior of this type has not been systematically studied using RP methods. However, our hypothesis is that the quality of environmental sites used for outings close to home is more likely to influence property values than the sites in a more broadly defined choice set. For our recreation analysis we therefore consider the influence of watershed quality on visits to sites within Wake County. Forty-eight water recreation sites were identified in the county.[4] Our survey provides information on 1187 respondents who reported making trips of this type between May and November 2002. Records on over 14,000 local trips are available for analysis, with each household taking on average 12 trips.

The water quality component of the database combines technical indicators of ambient water quality from twelve separate sources.[5] For this application we use readings from monitoring stations located in Wake County and focus on chemical measures. The specific variables used for the RUM analysis are total suspended solids (measured in lab nephelometric turbidity units), total phosphorus (measured in milligrams per liter), and ambient dissolved oxygen (measured in milligrams per liter). We provide detail on how these observations are used to characterize site quality in the following section.

6. Estimation and Results

RUM Estimation

We begin by describing construction of the recreation index using a basic water recreation RUM model. Estimation of a RUM model requires specification of the choice set, calculation of the price of a visit to each site, and attachment of environmental quality characteristics to each site. There are two possibilities for defining an object of choice in the choice set: a specific point in space based on a named destination, or a spatial unit defined by physical hydrology. The former is better suited for understanding visitor use and benefits for a specific site. The latter is preferred when the focus is more on water quality conditions in a general area. Defining choice alternatives based on watersheds aligns the spatial resolution in the choice model with the physical conditions that give rise to variation in water quality levels. By dividing the study area into high resolution watersheds the full variability in water quality across the landscape can be exploited in the model, and choices directly reveal distance/quality tradeoffs. For this reason we focus primarily on a watershed based choice set, returning briefly to a site-specific choice set below.

We define the choice set to be the set of hydrological (CH2MHill) zones described in section 2 and shown in figure 1b. Trips observed in the sample were assigned to one of the 80 zones. The RUM model's objective is to explain the choice of one of these zones for a local trip as a function of the implicit price and watershed quality in the zone. The resource cost of a visit is the round trip time needed to travel to the zone, calculated between the person's address and the center of each hydrological zone. GIS software was used to make these calculations for all sampled households and all zones. The average round trip travel time for trips observed in our sample is 35 minutes.

The CH2MHill study provided a qualitative expert assessment for each of the hydrological units included in our choice set. Due to the limited variability in the assessments, however, we focus on technical measures of ambient water quality to parameterize our quality variables. Our database contains ambient water quality readings taken from monitoring stations located throughout the county. Readings for total suspended solids (TSS), total phosphorous (TP), and dissolved oxygen (DO) taken in the county after January 1998 are used to construct the variables. Monitoring station readings were attached to a hydrological zone based on the location of the station generating the reading. The empirical distribution of all available readings attached to a hydrological zone was then used to generate summary measures. For phosphorous and suspended solids the 90th percentile in each zone is the summary measure, while for dissolved oxygen the 25th percentile is used. Table 1 contains a summary of these measures across the 80 hydrological zones, as well as a summary of watershed size.[6]

Our empirical specification for the conditional indirect utility function for a visit to a site in hydrological zone *k* is

$$V_k = \beta time_k + \delta size_k + \gamma_1 TSS_k + \gamma_2 TP_k + \gamma_3 DO_k + \varepsilon_k, \quad k = 1,...,80, \tag{14}$$

where the errors terms are distributed type I extreme value. Estimates of the utility function parameters are shown in table 1. The estimates are significant and consistent with prior expectations. In general people visit areas of the county that are closer to their home, have lower levels of TP and TSS, and higher levels of DO.[7] Accounting for the different units in which the pollutants are measured, under baseline conditions TP has largest disutility effect relative to TSS and DO.

Hedonic Estimates

The RUM model provides a characterization of preferences for recreation and water quality that is used to construct our quality adjusted recreation index. The division of the county into MLS zones is used to define the neighborhood for which access is defined. In particular, we define the index by

$$ECS_j = N_j^{-1} \sum_{i=1}^{N_j} \ln\left(\sum\nolimits_{k=1}^{80} \exp(V_{ki})\right) \Big/ \beta, \quad j = 1,...,19, \tag{15}$$

where N_j is the number of person-trips originating from MLS zone *j*. This provides an MLS zone-specific summary of the average benefit from a trip originating from the zone that is functionally dependent on quality levels and average household characteristics in that zone. The quality dependent access index is included as a spatially varying explanatory variable in our hedonic regression.

We use a non-linear function of distance to the nearest water body to proxy the residential amenity affect of water resources in the county. In conventional property value models it is often assumed that location on or near a lake is an amenity for the residents, which may influence property values. To compute our distance measure we obtained an Arcview shape file containing all lakes in the county. The distance between each house from all lakes was calculated and the distance to the nearest lake was determined. Since the amenity affect is likely to diminish and disappear with greater distance the following function was used to create the distance variable:

$$lakedist = \max\left[1-\left(d/d_{\max}\right)^{1/2}, 0\right], \tag{16}$$

where d is distance in miles and d_{max} is the cutoff point, set to ½ mile for this application. The index is between zero and one and is convex. Twenty-two percent of properties in the sample are within a half mile distant from the nearest lake.

Estimates from the hedonic model for lake distance and the recreation index are shown in table 2 under model 1, with the remaining parameter estimates given in table 1A in the appendix. The results are quite intuitive. Both the quality adjusted recreation index *and* proximity to lakes capitalize into housing prices as expected. Using complementary sources of data we show that recreation access is reflected in property values and changes in access conditions ((either through closer proximity or better water quality) can be measured with the hedonic model. This finding is consistent with our hypothesis that watershed services enter preferences through different channels, and is suggestive of the importance of considering these different channels for benefits assessment.

Diagnostics

Before considering policy uses of our model we examine the robustness of our estimates. In particular, we consider two possible sources of bias. The first is related to Parson's (1991) discussion of possible price endogeneity in travel cost models. The RUM stage of our model can be interpreted as a quality adjusted price index for recreation access.

Consistent estimation of the preference parameters used to construct the index is best achieved by a controlled experiment in which households are randomly located throughout the county and their subsequent recreation behavior observed. In a controlled situation the location-determined price of recreation access is exogenous. Absent this it is possible that location decisions and recreation behavior are simultaneously determined, confounding our ability to consistently estimate the price parameter in the RUM model. To partially gauge the extent to which this may be a problem in our RUM estimates we estimated the model using a sub-sample of people who were new arrivals to the county at the time they purchased their house. We speculate that new arrivals (who are less familiar with the county's geography than long time residents) would be less likely to choose a location based primarily on access to recreation sites. Any confounding affects present in the full sample should therefore be reduced in the sub-sample. In spite of the much-reduced sample size we find estimates of the RUM parameters that are nearly identical to their full sample counterparts. We conclude from this that our recreation index is not biased by the simultaneity problem described by Parsons. This is likely due to the fact that recreation and other environmental amenities, although important, are probably less important in determining location than first order factors such as commute time, school quality, etc.

The second source of bias we consider relates to the choice set construction for the RUM model. An alternative to the watershed-based choice set is to define the objects of choice to be specific sites. This definition increases the resolution in the price variable, but reduces resolution in the water quality variables. Because water quality is measured at the level of a hydrological unit the finer spatial resolution in choice definition does not increase the resolution in water quality measures. More importantly, the site-based definition reduces the geographic extent of the choice set. For example, in our local recreation application we identified 48 individual named sites. These sites are spread across 23 of the 80 hydrological units comprising the county. Defining the choice set based on the 48 sites limits the extent of variation in water quality in that less than one-third of the hydrological units are represented in the model, and water quality among these is based on only thirteen monitoring stations.[8] We estimated a RUM model with the 48 sites, attaching quality measures based on the hydrological unit in which the site is located.[9] Parameter estimates from this specification are less robust than from the hydrological zone choice set. A specification including TSS, TP and DO led to an insignificant sign for TP and counter-intuitive sign for DO. A specification including only TSS and TP produced results similar in magnitude to the hydrological zone model. We constructed the recreation index and estimated the same hedonic model as given above using this model. Results for the environmental variables in this specification are given in table 2 under model 2. We find qualitatively similar estimates as in our preferred model, although these results are much less stable to changes in other included variables than model 1.

Policy Example

The Raleigh News and Observer's lead article on June 30, 2005 featured the rapid growth of several communities in Wake County. Between 2000 and 2004, the fastest growing town in North Carolina was Morrisville (in western Wake County) with 122% growth. Five towns in Wake County grew by more than one-third during those four years. Such growth is due to the prosperity in the area, but it also brings problems. Since this paper has focused on the relationship between water quality and property values, we present some examples to illustrate the usefulness of our results. In related research (Atasoy et al. 2005) we have studied the effects of residential construction and residential land use on water quality using spatial econometrics and a micro panel data set for Wake County.[10] We can use the results from that paper to predict the effect on water quality due to the rapid growth in some of these communities. The predicted changes in water quality can then be used in the current model to infer changes in property values. Obviously, these examples consider only one effect of growth.

Morrisville on Crabtree Creek, grew by 6,376 people between 2000 and 2004 leading to the 122% growth. Morrisville lies in hydrologic unit W15 (a larger spatial aggregate than used here) in Atasoy et al. Since the data in that study ended in 1999, the new growth immediately follows the study period. The population growth was converted to new houses dividing by 2.3 persons per residence. This was then converted to new houses per square kilometer in the hydrologic unit to match the variable definition used in the Atasoy et al. water quality model. The spatial econometric results from the water quality model were then used to predict the change in total phosphorous from the change in housing stock. The additional houses by the end of 2004 are predicted to increase total phosphorous in the hydrologic unit by thirty percent. It would also be transported to downstream hydrologic units, but the decay is fairly rapid. There would be a 2.1 percent increase in the next downstream hydrologic unit, and it becomes negligible further from the original change.[11] These predictions are based on the housing stock once construction was complete. Because the rate of construction in Morrisville between 2000 and 2004 was far outside the range of the data used in Atasoy et al., we have not predicted the effects of the construction on water quality.

The predicted pollution changes were linked to the CH2MHill zones lying in the affected hydrological zones to analyze the approximate welfare effects of the changes. Column 2 of table 3 shows the average effect on property values for each of the 19 MLS zones included in the study, calculated using equation (13) and an annualization rate of 5%. These provide approximate annual household level welfare measures for the water quality decrease. The welfare impacts vary spatially from a maximum of approximately $25 per year in the affected area to essentially zero further away from the growth. The variability between these two extremes reflects the underlying hydrology and population distribution in the county. The largest effects are found in the areas of the projected growth, population centers near the growth areas, and the downstream neighborhoods.

A second community that is rapidly growing is Wake Forest on Smith Creek, where 4,539 residents were added for 35 percent growth over the four years. Because of the spatial layout, the houses per square kilometer are substantially lower for Wake Forest. Most of the growth took place in hydrologic unit W4 in the Atasoy et al. study. The increase in houses by 2004 is predicted to cause a 3.5 percent increase in total phosphorous in the hydrologic unit. For this scenario the level of construction is comparable to the range of our earlier data, so we can predict the effect of the construction of houses on the pollutant loadings as well. If the construction was spread evenly over the four year period, total phosphorous would increase by 4.5 percent. New construction also increases total suspended solids and would result in a 3 percent increase. Finally, in-stream transport would result in a 0.56 percent increase in TP and a 0.1 percent increase in TSS in the next hydrologic unit downstream.

Column 3 of table 3 shows the predicted welfare bounds of this scenario for the MSL zones in the county. As with the Morrisville scenario there is substantial variation in the welfare measures across MLS zones; the size, however, is an order of magnitude smaller. MLS zones 14 and 21 contain the projected growth and have the largest annual welfare decreases of $2 and $1 per year, respectively.

7. Discussion

There is widespread policy interest in measuring the economic value of enhancements in ecosystem services. Addressing the challenges posed by these policy needs requires methods capable of incorporating the multiple, spatially delineated pathways these services take in influencing people. For the most part, revealed preference methods have not been up to this task. They have relied on single choice margins, together with preference restrictions and spatial variation in the environmental service of interest in each application, to identify how each separate service contributes to well-being. As a result, consistent measurement of the separate influences of multiple amenities (or pollutants) has not been possible. In this paper we employ two data sources and a new strategy for linking models to address this problem. In particular, we illustrate how recreation site choices and property value data can be used together to gauge how three aspects of the services provided by an urban watershed capitalize into housing values. We find evidence that proximity to water resources, access to recreation sites, and the water quality at these sites are positively related to property values. Our analysis exploits two choice margins by recognizing that within a static framework the outcomes implied by one set of choices can be treated as "attributes" – conditional expectations of the types of choices that would be possible with a particular residential choice. Developing the model required new data collection, designed to reflect the need to map the spatial dimensions of housing markets and neighborhoods into the different spatial definitions for the hydrological areas that comprise watersheds. Publicly available data do not have the resolution required to link housing choices, recreation site selections, household characteristics, and watershed attributes. As a result, new data collection activities together with efforts directed at establishing consistency in the geographical roles of economic and hydrologic data have been important aspects of this research. While not necessarily exciting tasks, they do provide other dividends. It was possible to evaluate the environmental costs of rapid suburban housing growth in the county that is the focus of our study. The spatial resolution in our analysis of choice margins allowed us to take an issue from the current headlines and provide an economic measure of its environmental costs. Our policy experiments suggest there is substantial variation in the welfare impacts of water quality decreases, both in magnitude and across space from the different growth scenarios.

At this stage our analysis provides a proof of concept that consistent use of spatial linkages, together with an assumed hierarchy in individual choices, can help to recover separate roles for several of the environmental services we associate with urban watersheds. Our estimated bounds for the incremental environmental costs of residential growth to existing homeowners seem plausible. Nonetheless, these results are simply the first step in the process of enhancing the spatial dimensionality of non-market valuation methods. Analysis of the implications of alternative decisions for the spatial units of analysis, comparison of structural versus reduced form models, and expansions in the number of choices margins considered are all potential extensions to this logic.

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Notes

[1] We restrict our review to studies that that were published in refereed journals and used market sales prices. There are some other studies in government reports and filings in litigation. Many of these are discussed in Palmquist and Smith (2002). Other unpublished studies are cited in the papers discussed here.

[2] Cropper, Deck, and McConnell's [1988] simulation experiments suggest that when the independent variables in hedonic models are replaced with proxy variables or the specifications are likely to be incomplete, simpler specifications for the price function such as the semi log have superior properties based on estimates of the marginal willingness to pay.

[3] Our relatively low response rate led to concerns about non-response bias. To investigate the degree to which this may be present we compared the proportion of completed surveys to socio-economic characteristics at the census block group level using a grouped logit model. The results suggest people in blocks with a higher proportion of white residents, older homes, and recent arrivals to the area were slightly more likely to return the questionnaire. There was no significant effect due to median income or median house value. Thus, while whites may be slightly over represented in our sample of home owners, there is little evidence of systematic bias in the sample that would compromise our ability to gauge homeowners' use of water recreation resources.

[4] Our survey included a map with a legend listing sites identified a priori by us, as well as space for respondents to identify sites not included in the list. Water recreation was broadly defined to include both contact and near-shore uses of area resources.

[5] Chemical monitoring data were obtained from the NC Department of Environment and Natural Resources for both public and private monitoring networks. These include monthly readings from ambient monitoring stations throughout the county between 1994 and 2000 for 61 variables. Pollutant loadings from major NPDES point sources were collected from electronic and paper sources. Nine variables were collected from the monthly reports of these sources for the Neuse River. Four types of biological summaries are available. Single samples collected on benthic and aquatic habitat characteristics in August 2001 by CH2MHill for Wake County are

summarized in our database. Periodic readings for the state benthic communities were collected by NC Division of Water Quality from 1982 to 2003 for Neuse River Basin sites and from 1983 to 2001 for the Cape Fear River Basin. Additional data sources are as follows. Chemical data for four variables describing water quality for major lakes in the Neuse and Cape Fear watersheds are available periodically from 1981 to 2002. The US Geological Survey (USGS) also reports chemical and flow data for sites within the upper Neuse and Cape Fear basins monthly from 1989 to 2001. All these databases can be linked either through the latitude and longitude of the sampling location or other identifying information to our various geographic area definitions.

[6] To our knowledge our database provides the richest characterization of urban water quality used in an economic model. Nonetheless the monitoring station network is not sufficiently dense to individually cover every hydrological zone. Of the 80 zones in our model 33 are covered by a monitoring station, necessitating aggregation to cover the remaining. Our aggregation strategy followed the USGS definitions for increasing watershed size (i.e. 14-, 11-, and 8-digit aggregate units). For each zone missing a monitoring station we assigned a covered zone located in the same 14, 11, or 8 digit hydrological unit with preference given to the lowest level of aggregation available.

[7] The chemical measures tend to proxy conditions at sites perceptible to individuals. For example, suspended solids tend affect visible water clarity. Phosphorous levels are predictors of algae blooms and water smell, while dissolved oxygen is a predictor for the health of aquatic life.

[8] An argument in favor of ignoring the hydrological units that do not contain a named site is that they are not in any case appropriate for recreation use. Identification in RUM models, however, depends as much on observing sites that people *didn't* visit as well as those they did. Ignoring the non-favorable areas precludes the ability to model the choice *not* to visit them, and hence understates the potential impact of characteristics in those areas.

[9] It is possible that additional water quality monitors could be used to characterize quality in a specific site model if a different watershed aggregation level (e.g. 11-digit units) were used.

[10] In Atasoy et al. (2005) we use water quality monitoring data for total nitrogen, total phosphorous, and total suspended solids over a five year period. We control for agricultural sources and point sources of pollution. Instream transport of pollutants is captured by a spatial lag. The variables of primary interest are the new construction and the existing housing stock.

[11] Atasoy et al. (2005) also considered TSS and found that the existing housing stock did not affect TSS, although housing construction did have a significant effect, as expected.

Table 1: RUM Model Specification and Estimated Parameters

Variable	***Description***	***Estimate (t-value)***
travel time	Time in minutes for round trip from respondent's home to center of each hydrological unit	-0.074 (-154.62)
Size	Size of hydrological unit in square miles. Mean (std. dev.): 12.55 (9.36)	0.089 (110.07)
TSS	Summary of total suspended solids. Calculated for each hydrological unit as 90th-percentile of empirical distribution of readings. Mean (std. dev.): 65.36 (102.92)	-0.0016 (-20.15)
TP	Summary of total phosphorous. Calculated for each hydrological unit as 90th-percentile of empirical distribution of readings. Mean (std. dev.): 0.846 (0.132)	-3.099 (-62.05)
DO	Summary of dissolved oxygen. Calculated for each hydrological unit as 25th-percentile of empirical distribution of readings. Mean (std. dev.): 6.52 (0.857)	0.0680 (12.90)

Table 2: Hedonic Environmental Variables and Estimated Parameters

Variable	***Description***	***Estimate (t-value)***	
		<u>*Model 1*</u>	<u>*Model 2*</u>
lake distance index	Proxy for amenity impact of lake proximity $=\max[1-(d/d_{max})^{½},0]$, d = distance to the nearest lake, $d_{\max}$ = ½ mile	0.0277 (6.73)	0.0191 (4.72)
Index of recreation access	Average value of *ECS* from RUM model calculated from trips occurring in each MSL zone. Mean (std. dev.):	0.00126 (6.92)	0.0028 (31.67)

Table 3: Welfare Bounds for Growth Scenarios[a]

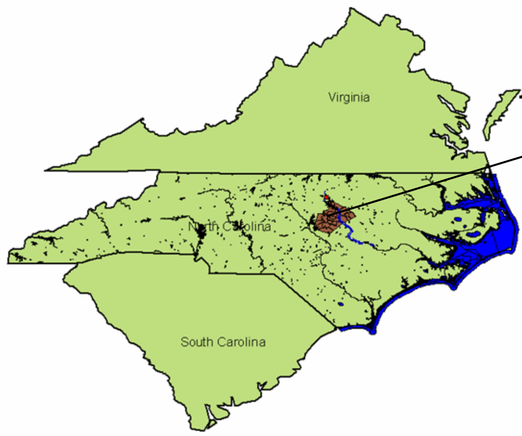
MLS Zone	*Morrisville Scenario*	*Wake Forest Scenario*
1	5.63	0.17
2	6.02	0.16
3	1.62	0.10
4	5.05	0.05
5	22.51	0.03
6	1.17	0.03
7	4.18	0.40
8	1.90	0.32
9	1.86	0.02
10	25.76	0.02
11	0.71	0.05
12	0.22	0.15
13	0.18	0.12
14	0.38	2.04
15	4.54	0.01
16	0.53	0.01
17	1.41	0.01
18	0.52	0.01
21	0.81	1.07

[a]average dollars per year per homeowner

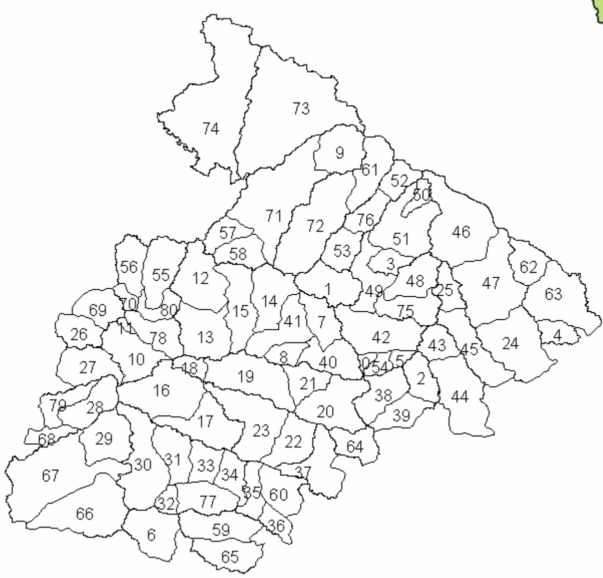
Appendix Table 1A: Remaining Variables from Hedonic Estimation Model 1

Variable	*Description*	*Estimate*	*t-value*
age	Age of structure, calculated as sale year-year built	-0.0008	-13.06
baths	Number of bathrooms	0.0175	15.22
acreage	Lot size in acres	0.0398	40.60
regheatarea	Main heated living area in square feet	0.0002	168.38
detgarage	Dummy variable indicating presence of detached garage	0.0574	16.85
fireplaces	Number of fireplaces	0.0685	38.53
deck	Deck area in square feet	0.0001	23.50
floordum1	Dummy variable indicating presence of hardwood floors	-0.0129	-4.91
scrporch	Screened porch area in square feet	0.0002	19.62
atticheat	Attic heated area in square feet	0.0002	39.64
bsmtheat	Basement heated area in square feet	0.0001	18.95
garage	Garage area in square feet	0.0002	69.92
poolres	Dummy variable indicating presence of residential swimming pool	0.0261	4.39
bsmtdum1	Dummy variable indicating presence of full basement	0.1021	31.34
bsmtdum2	Dummy variable indicating presence of partial basement	0.0936	31.89
walldum1	Dummy variable indicating presence of brick walls	0.0079	3.92
yrdum99		0.0308	27.54
encporch	Enclosed porch area in square feet	0.0002	10.80
opnporch	Open porch area in square feet	0.0001	14.39
condadum	Dummy variable indicating house is of condition A (highest)	0.1064	36.62
condcdum	Dummy variable indicating house is of condition C	-0.1063	-28.43
condddum	Dummy variable indicating house is of condition D	-0.2339	-18.94
commute	2000 census block mean commute time	0.0024	25.14
grade	Numeric grade assessed by revenue department	0.0073	173.02
Constant		10.3477	2170.79
R-squared	0.92		
Dep. variable	ln(price)		
# observations	38,817		

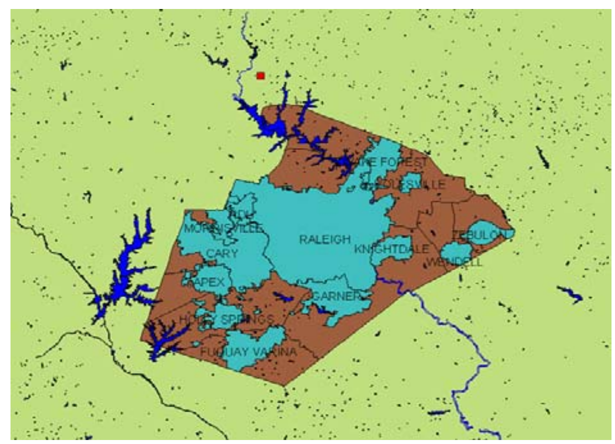
Figure 1: Economic, Hydrological, and Jurisdictional Divisions of Wake County



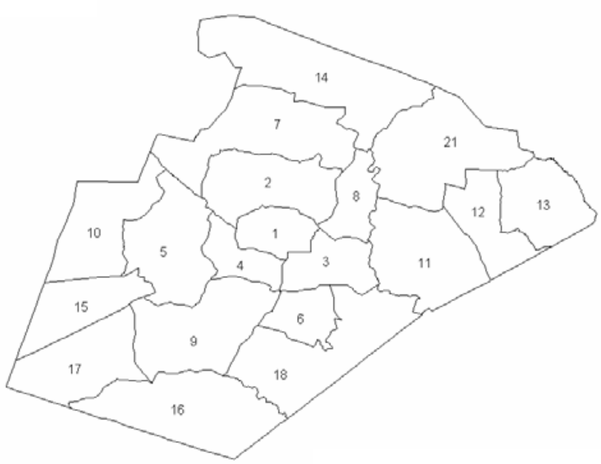
Panel a:
Wake County, NC



Panel b: Wake County sub-hydrological (CH2MHill) zones



Panel c: Major municipalities



Panel d: Wake County housing sub-markets (MLS) zones