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Spatial landscape indices in a hedonic framework: an ecological economics analysis using GIS

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Abstract

This paper develops a spatial hedonic model to explain residential values in a region within a 30-mile radius of Washington DC. Hedonic models of housing or land values are commonplace, but are rarely estimated for non-urban problems and never using the type of spatial data (geographical information system or GIS) available to us. Our approach offers the potential for a richer model, one that allows for spatial heterogeneity in estimation, and one that ties residential land values to features of the landscape. Beyond the traditional variables to explain residential values, such as man-made and ecological features of the parcel and distance to cities and natural amenities, we also hypothesize that the value of a parcel in residential land use is affected by the pattern of surrounding land uses, not just specific features of point locations. We have also created and added these variables to the hedonic model by choosing an appropriate area around an observation, and calculating measures of percent open space, diversity, and fragmentation of land uses, measured at different scales around that observation. These indices have, for the most part, been significant in the models. By including two of the landscape indices developed by landscape ecologists, we have developed a model that explains land and housing values more completely, by capturing how individuals value the diversity and fragmentation of land uses around their homes. © 1997 Elsevier Science B.V.

Keywords: Hedonic models; Spatial landscape index; Spatial heterogeneity; Geographical information system

1. Introduction

What happens to land, not just aggregate land but the spatial arrangement of land, is a topic of

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increasing interest to multiple disciplines. Land use is inextricably tied to public infrastructure demands that are more or less costly depending on their spatial distribution. Land use is almost synonymous with location externalities, i.e. visual, noise, waste, etc. Also, land use has environmental consequences that differ markedly depending on the pattern of remaining habitat and the size and proximity of disturbances to ecologically sensitive areas. The configuration of land is one of the major contributors to the quality of life.

For all these reasons, economists are becoming more interested in land use and its spatial distribution. From the landscape ecology perspective, the spatial arrangement of land uses is the starting point of many modeling approaches (Turner, 1987; Fitz et al., 1996). Joint ecological and economics modeling in this area will potentially have large contributions to the valuation of landscape amenities and the understanding of human impacts on ecosystems. One goal of ecological economics should be the integration of modeling approaches and relevant techniques. This paper hopes to promote that goal.

Facilitating this interest in landscape configuration is the increasing availability of the means for measuring spatial arrangement and distribution of land uses through the use of geographical information systems (GIS). GIS provides an obvious and intuitively appealing means of organizing and storing information that is spatially based, such as land records, natural resource features, and public infrastructure location, allowing easy inventory and recall. Landscape ecologists have used GIS data for many years, but now GIS data suitable for economic analysis is becoming available.

When asked what determines the selling price of a house, realtors reportedly answer 'location, location, location'. Traditional economic studies have attempted to capture location by access or distance measures, thereby reducing the spatial components of the model to a few uni-dimensional variables. If indeed this is the principal means by which space enters the problem, then the advantage of GIS-type data is solely in making distance measures more accurately or more easily computable.

But the importance of location in land values and land use determiation is not restricted to accessibility. Externalities characterize land use, and these externalities are spatially determined. What surrounds a property has a major influence on its value. Economists have attempted to capture this using neighborhood characteristics or indices of neighborhood quality based on income levels, crime statistics, and so forth. Once again, spatial considerations are reduced to uni-dimensional measures, in this case obtained from aggregate data such as Census statistics.

There are at least two problems with this approach. The first is that neighborhood delineations are arbitrary and misleading. Locational characteristics are more likely characterized by a gradient than by discrete levels that change abruptly over polygon boundaries. The second is that there may be more to locational amenity effects than the ones traditionally measured. Land use externalities include not only neighborhood effects such as crime rates, but also proximity to externalities such as traffic and industrial noise and visual amenities/disamenities. Individuals will also value *patterns* of land use surrounding a property. Patterns are characterized by different housing densities, different amounts and placement of open space, etc.

Some amenities or disamenities will be very specific to the particular property because they will be related to those visual and noise externalities that impinge directly on its inhabitants. Thus knowing the exact location and the land use surrounding that location may add explanatory power to a hedonic function. However, measurement of the amenity values associated with *patterns* of the landscape will also be facilitated by spatially explicit data. Landscape ecologists think in terms of *mosaics* of natural and human-managed *patches*, concepts that relate to the diversity and fragmentation of the surrounding landscape, a concern that is more pressing in a rural or regional landscapes than in the traditional urban setting where land use is more homogeneous when viewed at the landscape scale. Geographically referenced data makes calculation of measures of diversity, complexity, and fragmentation possible (O'Neill et al., 1988). These spatial indices and their use are described in Section 2.

In this paper we develop a hedonic model, introduced and discussed in Section 3, to explain housing values using traditional explanatory variables for structure and lot, location, and socio-demographic characteristics, and also explanatory variables for landscape pattern characteristics calculated using GIS. This hedonic model is of the counties in the Patuxent Watershed in Maryland (see Fig. 1). The work is part of a larger project at the University of Maryland, sponsored by the Environmental Protection Agency to bring together economists and ecologists to model land use change and the ecological impacts of these changes on the Patuxent Watershed of the Chesapeake Bay ecosystem in Maryland. The major contribution of this paper is the inclusion of landscape pattern indices, developed by landscape ecologists to describe the spatial arrangement of land use, in a hedonic model to capture the amenity effects of surrounding land use patterns on the selling prices of homes.

2. Spatial indices

Spatial landscape indices are used to quantify landscape pattern to reflect the ability of the landscape to support certain ecosystem functions. Landscape pattern is an integrative measure of an ecosystem's ability to provide habitat, prevent environmental degradation, and support other natural processes. While a definition of a well-functioning ecosystem is elusive, many have stressed the importance of looking at a variety of types of measures to capture characteristics indicative of health or decline (Costanza et al., 1992; Mageau et al., 1995). Spatial indices are used because even though ecologists may have evidence of a local ecosystem decline, that information does not necessarily translate into an ability to link cause and effect at a broad scale. Data on the impacts of human actions on plants or animals at a small scale may not be sufficient to distinguish between natural variability and decline of an ecosystem over a larger region (Costanza et al., 1993). Indices serve two main purposes; they provide a means to scale up our observations of local impacts to the regional level using knowledge of ecosystem processes and they allow us to consider a range of ecosystem processes when assessing ecosystem function or level of degradation. Indices allow us to analyze effects at a scale which is relevant from the human perspective of management and valuation.

In this study, landscape indices are linked to human values. We are testing whether diversity and fragmentation, which have known ecosystem effects, also influence how humans value the landscape. Humans, like other animals, have a preferred habitat and are exposed to land use externalities. Plants or animals may pay for a loss of desired habitat with smaller or more stressed populations, while humans literally pay higher prices for desirable living space as it becomes scarce. By modeling the factors that affect the value of land in residential use and therefore the factors that will affect the likelihood of land use change, we further our understanding of potential stressors to the ecosystem from human-induced land use change and the feedbacks between ecosystem change and human decisions. In this paper we are testing whether ecosystem patterns that directly and indirectly affect ecosystem function also influence human decisions. By modeling how humans value the diversity and fragmentation of the landscape, we further our understanding of the conflicts and compatibilities between human landscape values and ecosystem health.

The development of landscape indices has grown out of several areas including island biogeography, theories on effects of disturbance, and information theory. Island biogeography theory, developed by MacArthur and Wilson (1967), suggests that given fixed characteristics, a larger island will hold more species than a small one and that species number is a function of immigration and extinction rates. This theory has been applied, by analogy, to landscape patches. Patch size is thought to be positively correlated to species and/or habitat diversity (Burgess and Sharpe, 1981) and the ability of organisms to move between patches is thought to influence species persistence. Researchers have shown that patch area can be a significant predictor of number of tree and bird species (Rudis and Ek, 1981). More recent work has indicated that the amount of edge and interior

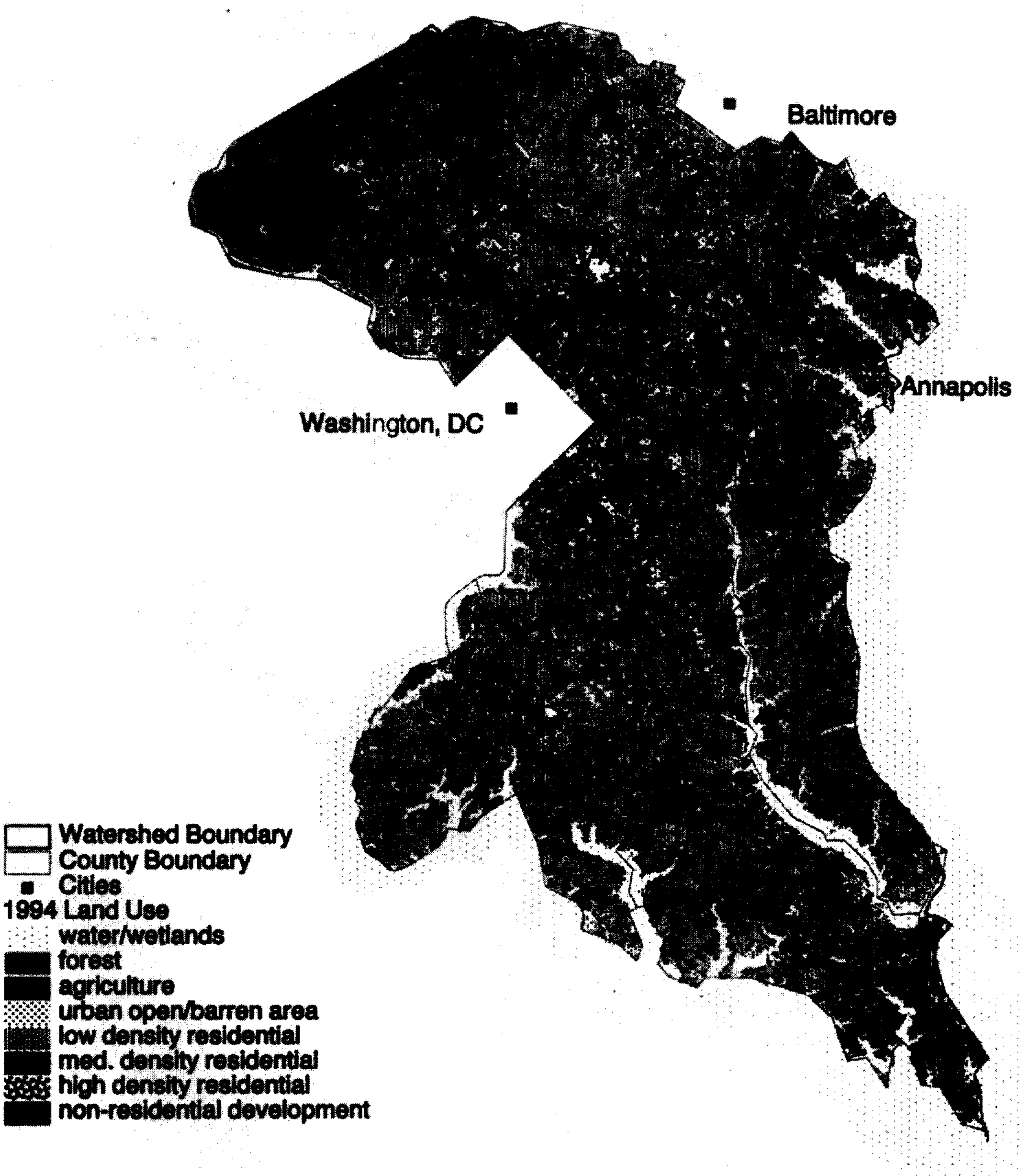

Fig. 1. Patuxent watershed counties 1994 land use and watershed boundary.

spaces influences abundance and diversity of organisms and other processes such as wetland functioning (Harris, 1988; Robinson and Quinn, 1988; Quinn and Harrison, 1988).

When humans divide the landscape, the result of imposing human-induced patches on natural patchiness can have far-reaching effects. Breaking the landscape into many small patches affects the landscape in two primary ways: by controlling movement and persistence of organisms and by controlling the redistribution of matter and nutrients (Turner, 1989). Fragmentation can alter nutrient cycling, water quality and quantity, and thus alter stream and riparian habitat due to the many ways in which hydrology structures stream ecosystems. Depending on the land use configuration and dominant physical processes, some patchiness may have a positive effect on ecosystem function, such as when patches serve to buffer developed areas. On the other hand, patchiness may weaken ecosystem functioning as indicated by work showing that size distribution of patches may affect a system's ability to recover from disturbance (Hunsaker et al., 1990).

As a landscape becomes more fragmented, the risk of losing species of plants and animals species increases (Pickett and White, 1985; Woodley et al., 1993). If patch size or contiguity falls below a level necessary to insure adequate resources or allow immigration, species will become extinct, at least locally. Edge-to-interior ratio, a measure of fragmentation, can indicate whether patches are small or spread out (e.g. a greenway). A lower edge to interior ratio might be expected to favor rare species as some species require a less disturbed interior habitat. The ratio of forest edge to interior has an effect on the magnitude of tree loss through blowdown and may influence risk associated with air quality, as edges are more susceptible to pollutants (Hunsaker et al., 1990). In terms of physical ecosystem function, such as wetland removal of sediment from runoff, patch shape may change an ecosystem's ability to provide certain functions.

Fragmentation indices can provide an idea of the risk of diversity loss and thereby provide a measure of ecosystem viability. Diversity is linked to viability in some systems because of the need for 'redundancy' to allow the system to absorb shocks (Perrings et al., 1995). While ecologists recognize that diversity is not synonymous with stability, diversity measures can be used to compare similar ecosystems to establish impairment. Some studies have shown that systems with lower diversity tend to be more easily invaded by exotic species (Moyle, 1986 cited in Schindler, 1990) and that pollution more easily affects nutrient cycles and ecosystem functioning in low-diversity communities (Schindler et al., 1985; Schindler, 1990).

Based on this ecological theory, landcover pattern indices can be used as a proxy for habitat requirements of plant and animal species and as an indication of changes in physical and chemical flows. The diversity index we use in this study measures heterogeneity of land uses based on a Shannon index (see Table 1). The index describes whether variables being considered are concentrated in a few categories or distributed among many categories. This index was developed to measure species diversity or dominance (Pielou, 1975), but has been applied to the landscape as a measure of land use diversity (O'Neill et al., 1988; Turner, 1990). The fragmentation index used in the hedonic models is the perimeter to area ratio. This ratio increases as land becomes more subdivided or as patches of a contiguous land use become more dispersed.[1]

While the above are the two landscape indices we investigated in the context of the economic hedonic model in the subsequent section, there are other landscape indices that could be adopted for future research and are included in Table 1.[2] Fractal dimension and the edge length between land uses measure features of the landscape related to patch shape. Fractal dimension, a type of edge-to-interior measure, may indicate the extent of human impact on the landscape as human impact tends to straighten natural, more convoluted, boundaries (O'Neill et al., 1992). The contagion index has been used in ecological modeling, and was found to be negatively correlated with water quality parameters in a study by Hunsaker et al. (1992) supporting the hypothesis that fragmentation plays a role in determining characteristics of runoff from the land, thereby

[1] See Table 1 for equations.

[2] For further information on indices see Turner (1989) and Baker and Cai (1992).

Table 1
Landscape pattern indices

Index	Equation	Description	Significance
Diversity[a]	$H = -\sum_k (P_k) \ln(P_k)$ where P_k = proportion of landscape in cover type k	Complexity of landscape measured as the average uncertainty of a given state	Measures extent to which landscape is dominated by a few or many landuses
Edge to interior ratio (fragmentation)	$R = \sum \frac{P_i}{A_i}$ where P = perimeter length, A = area of interior, i = land cover type	A reflection of patch size and shape	Measures potential loss of function of landuse due to decreased size or loss of interior
Fractal dimension[b]	$L = ks^{(1-D)}$ where L = boundary length, s = cell length or resolution of measurement, D = fractal dimension, k = estimated parameter	Degree that edges are convoluted vs. straight and uniform between landuse types	Measures extent of human change on the landscape
Edge length between landuses[c]	$E_{i,j} = \sum e_{i,j} L$ where $e_{i,j}$ = no. of interfaces between cells of types i and j, L = length of edge of cell	Similar to contagion but more specific to interactions between particular landuses	Can be used to assess flowpaths for overland movement of materials
Contagion[b,d]	$C = 2s \log 2 + \sum_m \sum_n q_{i,j} \log(q_{i,j})$ where $q_{i,j}$ = probability of landuse i being adjacent to landuse j, s = no. of observed landuses	Degree to which landscape is divided into many small patches vs. a few large patches	Measures increased risk that organisms will not be able to access needed resources
Lacunarity[e]	$\Lambda(r) = \frac{\sum S^2 Q(S,r)}{\sum [SQ(S,r)]^2}$ where $Q(S,r)$ = probability distribution of occupied sites from generated map, S = no. of occupied sites in window, r = length of window	Distribution of gap sizes between landuses; captures broad scale patterns of connectedness of landuses	May measure risk to species diversity

[a] Turner (1990).
[b] O'Neill et al. (1988).
[c] Hunsaker and Levine (1995).
[d] Turner (1989).
[e] Plotnick et al. (1993).

influencing stream and near-shore environments. Also, the contagion and lacunarity indices incorporate the importance of corridors and contiguous habitat types to provide appropriate migration routes and types of habitats for more mobile species. The lacunarity index, according to Plotnick et al. (1993) is a better measure of broad-scale landscape patterns than contagion because it puts the effects into a wider regional context.

3. The hedonic model

The region chosen for the EPA project is the Patuxent Watershed in central Maryland, one of the nine river basins of the Chesapeake Watershed and covering about 1000 square miles. This includes parts of seven counties, ranging from the Washington, DC suburbs and the state capital to predominantly rural counties at varying stages of development. This analysis investigates only the value of residential real estate and, to focus solely on spatial concerns, we avoid time series problems by considering only those properties for which transactions data exist for the year 1990.

Hedonic models are reduced form statistical models that seek to trace out, at a point in time, the locus of equilibrium transactions prices as a function of the characteristics of the heterogeneous real estate transacted. Innumerable applications exist in the literature dating from the 1950s. As real estate is a complicated good with many dimensions, differences in selling prices of houses will be dictated by a number of factors, including the quality of the housing structure on the property, neighborhood characteristics, the accessibility to the central business district, as well as the environmental amenities associated with the property. In the past several decades, environmental economists have used these types of models to reflect the contribution of environmental amenities to the selling price of a house. The first application in environmental economics (Ridker and Henning, 1967) tested the relationship between property values and air quality and found a statistically significant relationship.[3]

Recent environmental applications include: the value of agricultural erosion (Dorfman et al., 1996); the impact of hazardous waste sites (Michaels and Smith, 1990); recreational and aesthetic value of water (Lansford and Jones, 1995); and the amenity value of forests (Garrod and Willis, 1992).

The hedonic model estimated in this paper is as follows:

$$\boldsymbol{R} = \boldsymbol{\alpha} + \mathbf{S}\boldsymbol{\beta} + \mathbf{L}\gamma + \mathbf{G}\tau + \varepsilon, \tag{1}$$

where $\boldsymbol{R}$ is an $(n \times 1)$ vector of housing prices; $\mathbf{S}$ is an $(n \times k)$ matrix of structural characteristics; $\mathbf{L}$ is an $(n \times l)$ matrix of neighborhood charisteristics; $\mathbf{G}$ is an $(n \times m)$ matrix of spatial (GIS measured) variables (distances and indices); $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, γ, τ are associated parameters vectors; and ε is an $(n \times 1)$ vector of random error terms.

The traditional hedonic model includes the first three sets of explanatory variables described above. The structural characteristics included in this analysis are: age of house, type of construction material, lot size, and whether lot is waterfront or not. The locational characteristics, include census data on both ethnic composition (specifically, percent white) and income (specifically, percent low income, percent middle income, percent middle-high income and percent high income) of the Census block group in which the lot is found. Two of the spatial variables are conventional ones, but made easier to calculate using GIS. These include the distance to the central business district—here distance to Washington, DC; and 'accessibility'—the distance to the nearest major road.

Unlike past hedonic studies, however, we add two additional spatial variables in an attempt to capture the pattern of the landscape surrounding the parcel. The two ecological landscape pattern indices chosen from the array of measures described in Table 1 are diversity and fragmentation. To calculate these indices we aggregated the 25 land uses designated by the Maryland Office of Planning into eight broad land use types: agricultural crops; pasture; forest; wetlands and water; barren; high density residential; low and medium density residential; industrial and commercial. We argue that diversity and fragmentation are characteristics of the landscape that might matter to humans in valuing location because they offer a richer description of pattern. However, the effect that increases in these indices will have on prices is an empirical issue. Increasing diversity might adversely affect property values by introducing more chances for negative visual and noise externalities. However, diversity may have a convenience value signifying the proximity of important work, shopping, recreation and institutional destinations. Fragmentation might be considered more obviously undesirable. Holding diversity constant, increasing fragmentation signals a hodge podge of land uses. A high fragmentation index is synonymous with a checkered landscape, more potentially conflicting edges for any given distribution of land use shares and therefore a higher potential for negative locational externalities.

Confusion over the sign of expected effects may be very much tied to the issue of scale, another

[3] For further background information on hedonic models, see Freeman (1993).

issue that holds a prominent place in ecology, and potentially, in economics. When we consider a landscape are we considering the immediate neighborhood, the town, city or county? For a region or major city, one would expect that a diverse use of lands would be better for economic stability reasons and for proximity to important destinations. However, for the immediate neighborhood, mixed uses are generally far less desirable. In incorporating measures of landscape pattern, variation across scale needs to be accommodated.

In order to attempt to capture the scale issue in this analysis, we measured the diversity index and the fragmentation index at both a 0.1 km and 1.0 km radius surrounding each housing transaction, with the hope that the smaller region would capture the immediate neighborhood, i.e. what can be seen from one's house, and the larger region would encompass what was within an easy walk of the house. Intuitively, one might expect the sign on these variables to change depending upon the scale at which they are measured. In Fig. 2, an example of a land use buffer of 1.0 km radius is shown. Other spatial measures of land uses within the 0.1 and 1.0 km buffer included the 'percent of open space' (percent forestry and agriculture) and the 'percent of low density residential' land uses.

The extent of the market for a hedonic analysis is always an issue to be addressed. The market should contain all the options available to potential buyers. If the market is defined larger than individuals actually choose from, then the regression results will be biased. On the other hand, by limiting the size of the market, the investigator loses information, so the estimation may become less efficient. For this paper, a 30-mile radius of Washington DC was chosen as the extent of the market, since this is arguably approximately the maximum of a reasonable commuting distance to the city. This radius includes transactions that occurred in Annapolis (the capitol of the state of Maryland), Anne Arundel County, Montgomery County, Howard County, Charles County, Calvert County, and Prince George's County. Zero-one dummy variables for these counties are included in the hedonic regressions to capture differential tax rates and public services, as well as school system quality, perceived crime rates, etc. The housing transactions that are included in this analysis are shown in Fig. 3.

The data for the analysis draws from a vector formatted GIS database for the seven counties of the Patuxent Watershed, obtained from the Maryland Office of Planning, that maps 20 categories of land use (see Fig. 1). The map has been augmented with Census Bureau TIGER files that provide streets and highways, and GIS data on hydrological systems. In addition, we use data that describes land parcels and structures provided from the Maryland Tax Assessment Records. At the time of this study, no explicit geographical information (such as latitude/longitude data) existed in these files to allow them to be automatically mapped to the GIS database, requiring a tedious process of address-matching between databases and this only for a subset of parcels. Instead we used information from the Tax Assessment database, assigning each transaction for the hedonic model to the center of the 3000 ft. by 4000 ft. size grid that the State of Maryland Tax Assessment Office uses for their paper tax maps, and this information was geocoded into the GIS.

4. Results

Table 2 reports estimation results from a double log ordinary least squares estimation. This functional form uses the natural log of the continuous and unbounded variables in Eq. (1) in the estimation. This functional form leads to easy interpretation of the estimated coefficients. The coefficients are elasticities: the percent change in the dependent variable given a percent change in an independent variable. For example, a 10% increase in the distance to Washington will lead to a 1.7% decrease in the selling price of the house. The estimated coefficients for the structural and neighborhood characteristics have the intuitive sign and are significant.

The most interesting result to note is that for the percent open space variable. For the smaller buffer, the marginal contribution of more open space is positive and significant, so more open

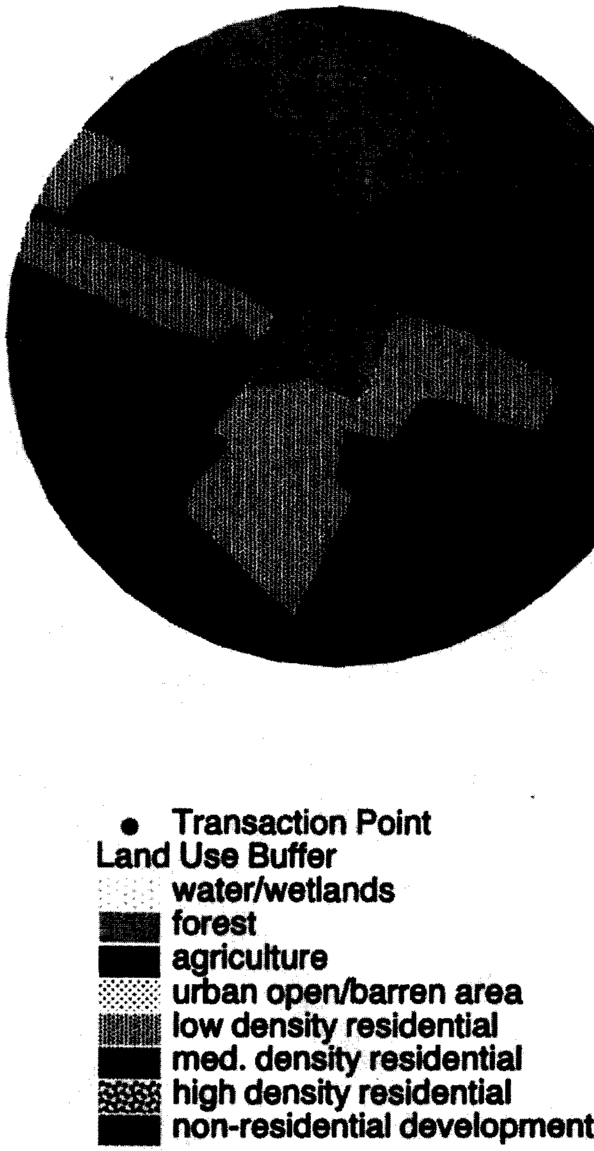

Fig. 2. Land use buffer of 2 km.

space in one's immediate neighborhood is valued. However, for the larger buffer, the percent open space variable is negative and significant. All else held constant, more forestry and agriculture in this larger measure of area around a housing transaction leads to a decrease in selling price. In this model specification, none of the diversity nor fragmentation indices are individually significant, but a Wald test of joint significance demonstrates that the small buffer measures are jointly signifi-

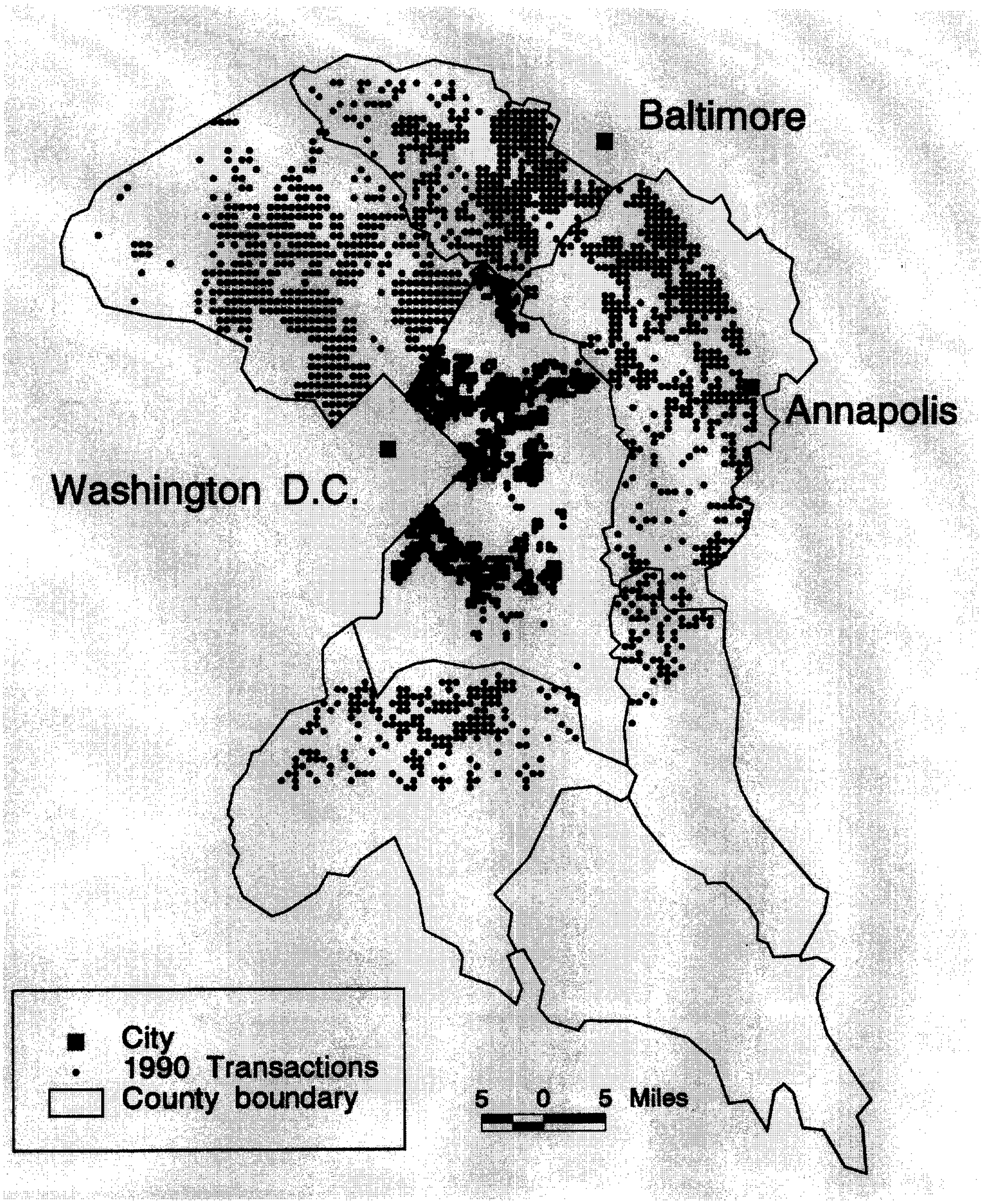

Fig. 3. Spatial index hedonic model.

cant at the 10% level, and the larger buffers are jointly significant at the 0.005% level, so that these variables together contribute to explaining land values. That is, the large buffer indices as a group contribute significantly to the explanatory power of the model.

Table 2
Double log model dependent variable: ln price

Variable name	Coefficient (t-statistics)	Variable name	Coefficient (t-statistic)
Constant	12.80** (285.42)	% Residential use (0.1 km buffer)	0.0081 (0.912)
Ln age of house	−0.124** (−27.40)	% Residential use (1.0 km buffer)	−0.030** (−3.55)
Waterfront	0.317** (6.21)	Annapolis (Maryland Capitol)	0.167** (5.06)
Ln distance to Washington, DC	−0.172** (−19.49)	Montgomery County	0.559** (37.77)
Ln lot size	0.172** (70.90)	Howard County	0.109** (10.58)
Ln access (distance to near major road)	0.016** (8.09)	Charles County	−0.156** (−13.33)
Wood structure	−0.013* (−1.79)	Calvert County	−0.301** (−10.59)
Diversity index (0.1 km buffer)	0.0005 (0.081)	Prince George's County	−0.125** (−8.87)
Diversity index (1.0 km buffer)	0.0060* (1.46)	% White in census block group	0.207** (15.26)
Fragmentation index (0.1 km buffer)	0.0036 (1.26)	% Low income in census block group	−0.464** (−12.91)
Fragmentation index (1.0 km buffer)	−0.0013 (−0.65)	% Middle income in census block group	−0.389** (−9.43)
% Open space (0.1 km buffer)	0.0189** (2.66)	% High income in census block group	0.456** (10.46)
% Open space (1.0 km buffer)	−0.034** (−5.34)		
R-squared	0.4744	Adjusted R-squared	0.4738

*Indicates statistical significance at the 10% level.
**Indicates statistical significance at the 5% level.

Up to this point we have assumed that the parameters of the hedonic function remain stable over the sampled area. This assumption is questionable. For one thing, this model presumes that the sampled area is one well-defined market. In reality, real estate markets have no clearly defined boundaries, but might be better characterized as having sliding boundaries. Certainly there may be households who work in Washington DC and considered the entire 30 mile range in choosing location, but there will be others, increasing in numbers as we travel away from Washington, whose employment location and implicit housing market is centered elsewhere. The boundaries of a housing market for one household will not naturally align with those of another. This suggests that the nature of the market may be slowly but continually changing as we move outwards from Washington. Looked at a different way, even if we were to assume a well-defined market, we might argue that because the nature of the landscape changes from fairly dense urban and suburban housing to rural regions as we move outward, the marginal value of slightly more open space, or diversity, or access, etc. may change as we move into dramatically different landscape patterns. For both these reasons, we investigate the possibility that the hedonic model exhibits spatial heterogencity.

In this second part of our analysis, we consider the possibility that the hedonic function varies continually over space, reflecting a series of interrelated submarkets with sliding boundaries. This model is known as the *spatial expansion model* in geography and allows the contribution of a housing characteristic to a property's value to change over space. For example, the value of open space might be higher in more urban areas relative to rural areas, where there is a scarcity of open space. Given the population density heterogeneity of our data over space, this model has strong appeal. To test this hypothesis of spatial heterogeneity with respect to our spatial variables, we employ a varying parameters model where the parameters vary linearly and quadratically with distance from Washington DC. Specifically, the model is expressed as:

$$\boldsymbol{R} = \boldsymbol{\alpha} + \mathbf{S}\boldsymbol{\beta} + \mathbf{L}\boldsymbol{\gamma} + \mathbf{G}\boldsymbol{\tau} + \boldsymbol{\varepsilon}$$

where

Table 3
Varying parameters model: quadratic in distance to Washington DC dependent variable: ln price

Variable name	Coefficient (t-statistic)	Variable name	Coefficient (t-statistic)
Constant	13.22** (164.21)	% White in census block group	0.102** (7.15)
Ln age of house	−0.128** (−28.45)	% Low income in census block group	−0.340** (−9.26)
Waterfront	0.343** (6.82)	% Middle income in census block group	−0.288** (−7.026)
Ln distance to Washington, DC	−0.309** (−12.07)	% High income in census block group	0.465** (10.75)
Wood structure	−0.034** (−4.75)	Ln lot size	−0.041* (−2.46)
Annapolis (Maryland Capital)	0.121** (3.70)	Ln lot size × distance to WDC	0.026** (13.65)
Montgomery County	0.568** (35.40)	Ln lot size × distance	−0.0007** (−13.45)
Howard County	0.115** (10.67)	Ln access (distance to near major road)	−0.103** (−13.73)
Charles County	−0.177** (−14.03)	Ln access × distance	0.014** (17.19)
Calvert County	−0.244** (−8.37)	Ln access × distance	−0.0003** (−15.92)
Diversity index (0.1 km buffer)	0.207** (5.78)	% Open space (0.1 km buffer)	0.0061 (0.160)
Diversity index × distance (0.1 km buffer)	−0.025** (−5.43)	% Open space × distance (0.1 km buffer)	0.0026 (0.51)
Diversity index × distance (0.1 km buffer)	0.0006** (4.70)	% Open space × distance (0.1 km buffer)	−0.000040 (−0.28)
Diversity index (1.0 km buffer)	0.053* (2.23)	% Open space (1.0 buffer)	−0.109** (−3.13)
Diversity index × distance (1.0 km buffer)	0.0045* (−1.45)	% Open space × distance (1.0 km buffer)	0.0077* (1.71)
Diversity index × distance (1.0 km buffer)	0.00009 (0.991)	% Open space × distance (1.0 km buffer)	−0.00016 (−1.20)
Fragmentation index (0.1 km buffer)	0.058** (3.17)	% Residential use (0.1 km buffer)	0.337** (6.27)
Frag Index × distance (0.1 km buffer)	−0.0089** (−3.32)	% Residential use × distance (0.1 km buffer)	−0.040** (−6.05)
Frag Index × distance (0.1 km buffer)	0.00024** (3.586)	% Residential use × distance (0.1 km buffer)	0.0011** (5.85)
Fragmentation index (1.0 km buffer)	−0.027 (−1.11)	% Residential use (0.1 km buffer)	−0.194** (3.35)
Frag index × distance (1.0 km buffer)	0.0035 (1.01)	% Residential use × distance (0.1 km buffer)	0.015* (2.14)
Frag index × distance (1.0 km buffer)	−0.000095 (−1.05)	% Residential use × distance (0.1 km buffer)	−0.0031* (−1.62)
R-squared	0.493	Adjusted R-squared	0.492

*Indicates statistical significance at the 10% level.
**Indicates statistical signifcance at the 5% level.

$$\tau = \lambda_0 + \lambda_1(\text{distance to DC}) + \lambda_2(\text{distance to DC})^2 \quad (2)$$

The results for the quadratic parameters model are reported in Table 3.

The results reported in Table 3 suggest that the marginal attribute prices for both access to major roads and lot-size vary significantly with distance. These marginal prices begin low, increase and then decrease again with distance from Washington. The functional form of the estimated equation is slightly more complicated to interpret than the simple log linear model. In the spatial expansion model, the coefficients still relate to elasticities, but these elasticities change depending upon the distance from Washington.

For example, the elasticity of selling price with respect to lot size varies from 0.052 on the border with Washington, to 0.20 at the maximum elasticity, which is reached at 18.4 miles from Washington, and then decreases to 0.10 at the 30-mile mark. While the elasticity is always positive, i.e. additional land is always better, the initially counter-intuitive result that the elasticity is smaller closer to Washington than further away can be explained by realizing that an elasticity measures a percent change and that because housing prices very close to Washington are already high due to its location, the *percentage* addition is small (although in absolute dollars, the extra piece of land might be worth more).

The most interesting difference between the two models is the effect the change in functional form has on the estimated coefficients for the landscape diversity and fragmentation indices. In the first model, none of the individual pattern indices was statistically significant at the 5% level. However, once we allow the contributions to property selling price of these variables to change with distance from Washington DC, the effect is striking. Now each estimated coefficient for the 0.1 km buffer diversity index and the 0.1 km buffer fragmentation index is statistically significant at the 5% level. (In addition, for the 1.0 km buffer diversity index, two out of three of the estimated coefficients are statistically significant at the 10% level.)

For both the fragmentation and diversity indices, measured at the 0.1 km buffer, the elasticity of selling price with respect to a change in the index, is negative over most of its range. This suggests that increases in both diversity and fragmentation in the immediate neighborhood of the house are not generally desirable features. Only in the immediate proximity of Washington, DC and at the extreme outer edge of the sampled region is an increase in diversity or fragmentation considered a desirable feature. One possible explanation for this is that in the highly developed, almost urban, Washington, DC suburbs, diversity and fragmentation are more highly valued as they result in amenities such as walkable access to small shopping areas and public infrastructure such as schools. For the more remote suburbs, where buyers have selected for more space and privacy, diversity and fragmentation of land uses signals land use conflicts brought about by the intrusion of office parks or larger strip malls. Finally, where rural land predominates and conveniences (such as shopping) are scarcer, diversity and fragmentation again become valued.

5. Conclusions and further research

This paper has reported our initial explorations using landscape ecology indices in a spatial hedonic framework. By including two of the landscape indices developed by landscape ecologists, we have developed a model that explains land and housing values more completely, by capturing how individuals value the diversity and fragmentation of land uses around their homes. In particular we have found that the marginal contribution to selling price of increased diversity and fragmentation changes in different landscape settings (urban, suburban, rural).

A number of elements of these results are interesting and have potential policy ramifications. First, we find empirical evidence that the nature and pattern of the land uses surrounding a parcel have an influence on the price, implying that people care very much about the patterns of landscape around them. Second, we note that the effect on price of many features of the landscape is different depending on whether the parcel is in a highly developed area, a suburban area, or a relatively rural area. We are currently refining this hedonic model by including more spatial econometric techniques, furthering our earlier preliminary research on this topic (Geoghegan and Bockstael, 1995). The combination of spatial indices and explicit modeling of spatial interactions among observations using spatial econometric techniques should yield interesting results.

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