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Working Paper 02_02 February 2002

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JEL Classification:
Q24, R14, R21
Keywords:
hedonics, sprawl, open space, satellite imagery

ABSTRACT

Urban areas can contain public parks, protected forests, unprotected (or undeveloped) forest areas, and trees growing around a house or in the neighborhood surrounding the house. Each type of forest cover provides different amenities to the homeowner and to society at large. In particular, while trees on a parcel or in a neighborhood may add value for homeowners, the ecological value of these trees as habitat is far less than large, unbroken parcels of forest. We explore different definitions of forest cover and greenness and assess the relative value of these different types of forest cover to homeowners. Using data from the Research Triangle region of North Carolina, we test the hypothesis that trees on a parcel or in the neighborhood around that parcel are substitutes for living near large blocks of forest. The findings have implications for land use planning efforts and habitat conservation in particular.

INTRODUCTION

Forest cover in an urban setting takes many shapes and forms. Urban areas can contain public parks, protected forests, unprotected (or undeveloped) forest areas, and trees growing around a house or in the neighborhood surrounding the house. Each type of forest cover provides different amenities (or a probability of disamenities as undeveloped parcels are developed) to the homeowner and to society at large. In particular, while trees on a parcel or in a neighborhood may add value for homeowners, the ecological value of these trees as habitat is far less than large, unbroken parcels of forest.

In this paper, we explore different definitions of forest cover and greenness and assess the relative value of these different types of forest cover to homeowners. Using data from the Research Triangle region of North Carolina, we test the hypothesis that the contributions of trees on an individual property, or in the neighborhood around that property, is conditional on whether the property is adjacent to or near large parcels of forest. This tells us something more about the substitution and complementarity of private, neighborhood and public forests. Our findings have implications for land use planning efforts and habitat conservation in particular.

Many studies over the past three decades have suggested that people should be willing to pay more to live near forests. For example, studies have suggested that the scenic quality of a town is increased by tree cover, but not that houses are more valuable (Schroeder and Cannon, 1983; Schroeder and Cannon, 1987; Civco, 1979). Previous studies have focused primarily on distance to public forests (see Tyrvainen and Miettinen, 2000; More et al., 1988; Luttik, 2000). A few studies have looked at distance to a variety of land uses and open space definitions (for example, Mahan et al., 2000; Lutzenhiser and Netusil, 2001; Smith et al., 2001) or the proportion of open space or other land uses in the neighborhood around a house (Irwin and Bockstael, 2000a and 2000b; Acharya and Bennett, 2001). Many of the studies that quantify the impact of open space on housing focus on public open space. In the Research Triangle, forests are the dominant landscape (i.e., environmental) features. Analyzing only public forests in the region would ignore the largest area of forests, those in private hands.

Our study extends the work in this area with a focus on specific measures of forest cover. We explicitly explore the interactions between a variety of forest variables that capture different services offered by forest cover. Using GIS technology and satellite data that measures the "greenness" of 30-meter squares, we are able to construct measures of greenness and forest cover at the property level. The continuous measures of "greenness" complement data on aggregate land use classes and provides a more complete picture of how a property fits within the neighborhood. The data also provide the researcher with increased flexibility in identifying blocks of forest with particular characteristics. In this analysis, we identify 40 acre and greater blocks of forests, which are believed to offer valuable habitat for wildlife.

Section 2 presents some background information on a variety of studies examining the value of forests and greenness to homeowners. In Section 3, we explore the forest cover and greenness variables used in this research and present some quantitative descriptions of these variables based on correlations and factor analysis of these variables. In Section 4 we present a hedonic price model that uses the greenness and forest cover variables described in Section 3, and Section 5 offers some conclusions.

BACKGROUND

Forest Benefits

The aesthetic value of old, large trees has been shown to increase the attractiveness of town streets (Schroeder and Cannon, 1983; Schroeder and Cannon, 1987; Civco, 1979) and may positively affect the psychology of residents (Sheets and Manzer, 1991). In a town setting, trees at intermediate and far visual distances positively impacted a town's scenic quality, while trees at intermediate distances provided the largest increase in scenic quality[1] (Brush and Palmer, 1979). Increased development intensity has the strongest negative impact on scenic quality with vegetation providing a positive influence (Anderson and Schroeder, 1983; Civco, 1979). Similarly, the natural vegetation of urban parks enhances scenic value while manmade objects decrease visual quality (Schroeder, 1982).

Urban forests provide a wide range of benefits beyond just the aesthetic, including reducing solar radiation, limiting runoff, absorption of urban noise, modifying air quality, improving human health and providing wildlife habitat (see Dwyer et al., 1992 for a more complete discussion). Bird diversity was found to vary between urban and suburban landscapes due to differences in forests structure and tree density (DeGraaf, 1985). In urban settings, wooded parks provided the best habitat for bird species with some evidence that tree-lined streets provided flight corridors (Fernandez-Juricic, 2000). Urban forests protect water quality by reducing the amount of runoff (7%, Dayton, Ohio, to 11%, Sacramento, California) and thus reducing the sediment running into streams (Xiao et al., 1998; Sanders, 1984).

The forest derived human health benefits include improved air quality, decreased urban noise levels and reduced psychological stresses. Urban trees reduce regional air pollutants (Ozone, PM_{10}, NO_2, SO_2, CO) by 1% to 3% of anthropogenic sources (Scott et al., 1998; Nowak, 1994). Yet, natural emissions of hydrocarbons, mainly from forests, have been found to be as large as anthropogenic sources possibly masking improvements in other air quality indicators (Chameides et al., 1988). Forest belts may reduce and/or mask urban noises by as much as 50% (Huang et al., 1992).

[1] Distances were defined as "a near zone within which individual leaves of trees could be discerned; a middle zone in which the forms of trees could be discerned; and a far zone in which the shapes of trees could not be discerned" (Brush and Palmer, 1979).

Empirical research has confirmed what many have long believed, that trees and natural environments improve psychological well being over scenes of urban settings (Hull and Ulrich, 1991; Schroeder and Lewis, 1991). Specifically, “people viewing visual images of trees and other vegetation have slower heartbeats, lower blood pressure and more relaxed brain wave patterns than people viewing urban scenes without vegetation” (Schroeder and Lewis, 1991). If urban forests do not actually protect you from getting sick, research has shown “that recuperation was faster and more complete” for patients viewing natural scenes compared to urban surroundings (Urlich et al., 1991).

Increasing the forest cover in a city reduces summer time heat more that it increases wintertime cold (Sailor, 1997). Planting trees located around residential structures may reduce both cooling and heating costs due to reduced summer heating and a wind-shielding effect (Huang et al., 1990). Savings of 1.9% to 2.5% on cooling costs have been estimated per residential tree, providing a strong financial incentive to choose housing locations with tree cover (Simpson and McPherson, 1998).

Forests have a mixed and unresolved impact on the development of adjoining communities. A recent debate highlighted the uncertainty of the impact of parks and green spaces to either foster neighborhood social ties or to create barriers to community interactions (Solecki and Welch, 1998; Gobster, 1998). Stronger neighborhood social ties have been documented around common spaces with higher levels of vegetation than similar common spaces lacking such trees or other green vegetation (Kuo et al., 1998). Yet not everyone living near parks or urban forests utilize such spaces (Bixler and Floyd, 1997), and crime is often cited as a reason to avoid densely wooded areas (Talbot and Kaplan, 1984).

Valuing the Forest in Real Estate

Many real estate professionals agree that houses with mature trees are preferred to comparable houses without mature trees (Dombrow et al., 2000). Trees and associated forest cover may provide benefits from increased privacy, improved aesthetics or enhanced recreation opportunities. Choosing a location with close proximity and/or desired views of a forest reserve can provide these forest-related benefits.

Proximity to Forests: Due in part to the broad array of data collection methods, the various studies show mixed significance of increasing tree cover or proximity to forest parks and housing prices. Two studies have suggested that housing values decrease rapidly as the distance from urban parks increase with the positive price effect declining to near zero in less than a half mile (More et al., 1988; Tyrvainen and Miettinen, 2000). Yet a similar study reported difficulty in finding a significant correlation with park proximity and housing values (Luttik, 2000). The presence of trees has been found to increase the selling price of a residential unit from 1.9% (Dombrow et al., 2000) to 4.5% (Anderson and Cordell, 1988) to 7% (Payne, 1973). However, the variable measuring forest cover can lack robustness, decreasing the reliability of the coefficients (Powe et al., 1995).

View of Forests: Another method of valuing forests has been to analyze the improvement in visual quality of trees or forest cover. Separating the effect of visual improvements from forest proximity can be quite difficult. Distance to a forest provides some measure of the recreational value while tree cover on a residential lot incorporates many more benefits of urban forest (i.e., noise reduction, summer cooling, wildlife habitat, psychological health, pollution reduction, etc). Aesthetic qualities largely comprise the value of a forest view. These aesthetic values have been documented on a limited scale, with residential housing prices varying from 4.9% with a forest view (Tyrvainen and Miettinen, 2000) to 8% with a park view (Luttik, 2000).

The Use of Remote Sensing and Satellite Imagery

Data collection has remained a primary obstacle to conducting hedonic price studies with forest variables. Hedonic studies often rely on data collected by private or governmental organizations such as the multiple listing service, which rarely contain information on tree cover (Dombrow et al., 2000). Photographs of houses have been used to actually count the number of trees per lot (Anderson and Cordell, 1988). Other researchers have used small data sets (60 to 300 observations) in order to conduct on-site tree inventories, accessibility to green spaces and quantify the view of adjoining properties (Thompson et al., 1999; Luttik, 2000; Morales, 1980). A large literature is being developed using maps and geographic information systems (GIS) to analyze environmental amenities (More et al., 1988; Powe et al., 1995; Geoghegan et al., 1997; Irwin and Bockstael, 2000a and 2000b; Tyrvainen and Miettinen, 2000; Acharya and Bennett, 2001).

Using aerial photographs to delineate vegetation types has a long history and is well-documented (Kadmon and Harari-Kremer, 1999). A decade ago, aerial photography was used to accurately measure the visual impacts of development on hillsides (Schroeder, 1988). Today, using satellite remote sensing, land cover and vegetation indices can be constructed over large multi-county areas (Owen et al., 1998; Geoghegan et al., 1997; Leggett and Bockstael, 2000; Acharya and Bennett, 2001; Mahan et al., 2000). The use of remote sensing data has allowed economists to join with landscape ecologists to include spatial and vegetation indices in hedonic models. Geographic information systems (GIS) provide a means of organizing very large datasets spatially and have been used to assess urban forests and green-spaces (Pauleit and Duhme, 2000; Dwyer and Miller, 1999).

SEEING THE FOREST FOR THE GREEN: UNDERSTANDING GREENNESS

In this study, we explore the impact of a variety of forest cover and greenness measures on housing prices in the Research Triangle region of North Carolina. Research Triangle is a rapidly urbanizing conglomeration of 3 to 15 counties, depending on the definition. This study focuses on Durham and Orange Counties, two representative counties at the core of the Triangle. From the technology and employment centers of southeast Durham County to the rural northwest corner of Orange County, a spectrum of residential housing choices exist within the integrated housing market. The city of Durham (pop. 170,000) dominates the urban housing market while Chapel Hill (pop. 45,000) and to a lesser extent Carrboro (15,000) and Hillsborough (pop. 5,000) provide small town atmosphere. Discussions with realtors indicate that school quality and general desirability create a premium for living in Chapel Hill.

Measuring Greenness and Forest Cover

Before we being our discussion of the hedonic price functions, we start with an exploration of the forest cover and greenness variables employed in this study. Most studies in environmental economics employ some measure of distance to public parks and open space or, more recently, the percentage of open space near a parcel. In addition to several different variables based on distance to forest or parks, we use greenness of the parcels themselves as measured by satellite images.

"Greenness"

We measured the "greenness" of the parcels and surrounding area using Landsat TM coverage of the two-county region. The satellite data divides the area into 30m by 30m cells or pixels. From this data, the Normalized Difference Vegetation Index (NDVI) was calculated for each 30m by 30m or pixel (Rouse et al., 1974). The NDVI is a ratio of the reflectance in specific spectral bands measured by Landsat TM, which is monotonically related to the amount of leaf area within each pixel. In addition, a quadratic discriminant analysis was used to classify each pixel to one of four land cover categories: water, forest, sparse vegetation (for example, lawns and golf courses), and developed (for example, built surfaces, roofs, or pavement). Training data for the quadratic discriminant analysis was obtained from high-resolution aerial photos of the region. Each pixel was classified into the land cover class that it was statistically most likely to have come from (i.e., the class it was spectrally most similar to). A modest error-assessment was conducted using known cover types from the region.

In a GIS database, the housing parcel map was overlaid on the pixel map. For each parcel, we calculated the mean "greenness" or mean NDVI index for the pixels in that parcel (mean greenness). In addition, we generated the proportion of the parcel that is forested, covered with sparse vegetation, water and developed based on the proportion of the total pixels in the parcel in which the category was the dominant land cover (*prop_for, prop_veg, prop_dev*).[2] We then used these variables to create a rough estimate of the number of acres in each pixel were devoted to each land cover type (*acres_for, acres_veg, acres_dev*).

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[2]Water was the excluded category in the regression analysis presented in Section 4 of the paper.

Institutional Forests

The Triangle area, and Durham and Orange Counties in particular, contains a number of institutional forests located close to or within the residential and commercial areas of the counties. In addition to state parks and federal lands (including Army Crop of Engineering land near two local reservoirs), Duke University and North Carolina State University own several large tracts of forest in the two counties. These forests offer opportunities for recreation in addition to aesthetic value. These forests are mapped in a GIS mapping system along with the housing parcels. Figure 1 shows the location of institutional forest areas in the whole Triangle region. Figure 1 provides a view of Durham, Orange and Wake Counties. The data for this study, from Orange and Durham Counties, comprises the two counties encompassing Durham and Chapel Hill in the upper left section of the map.

Using a GIS cover of publicly owned land, we measured the minimum Euclidean distance in meters from the edge of each parcel to the nearest institutional forest (inst_dist). An adjacency dummy variable (inst_adj) was coded 1 if a parcel was within 20 meters of the institutional forest. A buffer was included to account for GIS error in either the parcel coverage or the forest boundary map. Approximately 42 parcels in the final data set were adjacent to the institutional forests, of which 40 were located in Durham County. Finally, we created an interaction term between the distance from a parcel to the nearest institutional forest and the mean greenness of the parcel (instXgreen). This variable proxies for the interaction between parcel greenness and proximity to institutional forests.

Private, Undeveloped Forest Blocks

In addition to institutional forests, privately owned forest covers a significant proportion of the Triangle area, especially outside the urban areas of Durham and Chapel Hill. According to a report prepared for the Triangle Land Conservancy, "forests important to wildlife are hardwood and mixed forests at least 40 acres in size with no or only slight disturbance by human activities (Ludington, Hall and Wiley, 1997)." We identified blocks of privately held forest 40 acres or larger containing no developed pixels, water or sparse vegetation using the pixel-level data on land cover.[3] These blocks were created without reference to ownership and may contain multiple parcels with different owners. As Figure 1 shows, the parcels are spread throughout the area.

Using the map of forest blocks, we created the same variables that were created for the institutional forests. We measured the distance from each parcel to the nearest private forest block (priv_dist) and created a dummy variable for adjacency to a private forest (priv_adj) if the parcel was within 20 meters of the forest block. Seven hundred and seventy-two parcels were adjacent to a private forest block, of which 228 are located in Durham County. Finally, we

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[3] The forest land cover category contains deciduous, mixed and conifer forests, however the classification is most robust at the aggregate category of "forest".

created an interaction term between the distance from the parcel to the nearest private forest block and the mean greenness of the parcel (privXgreen).

Blocks of Development

Finally, we used the land cover map to identify developed or built areas of 10 or more acres similar to the forest blocks. For each parcel, we calculated the distance from the parcel to the closest block of developed land (dev_dist). This variable should capture the proximity of the parcel to smaller shopping centers outside the major employment centers or areas of dense development. The variable may also provide an indirect measure the greenness of the neighborhood in which the parcel is located. Figure 2 displays the location of the developed blocks, which are mostly clustered around Durham and Chapel Hill in our study area.

Correlation of Greenness Variables

One would suspect that several of the variables described above play a similar role in people's utility and housing choices with respect to environmental variables. Before discussing the regression results, Table 1 presents the correlation matrix for these variables to investigate this hypothesis. Almost all of the correlation coefficients are significant at the 1 percent level. As expected, the mean greenness of the parcel is highly correlated with the proportion of the parcel that is forested. Mean parcel greenness and the proportion of the parcel that is forested are positively correlated with adjacency to private forest blocks and distance from developed blocks. Parcels located adjacent to private forest blocks are greener on average than other parcels, while parcels located away from developed blocks are also greener all else equal. Finally, the number of acres of forest within a parcel is positively correlated with adjacency to a private forest block and the acres of sparse vegetation within the parcel.

The variable measuring distance to developed blocks is positively correlated with distance to institutional forests and negatively correlated with distance to private forest blocks. This suggests that in Orange and Durham Counties, parcels located closer to institutional forests are also located closer to developed areas, while parcels located closer to private forest blocks are farther from developed areas. The protected institutional forests seem to be located near urban areas of the two counties.

Finally the year in which the house was built is negatively correlated with distance to private forests. This may imply that newer houses are being located away from developed areas and closer to private, developed forest blocks. As the Research Triangle area expands, most of the building is going to occur on privately owned forest tracts, so this association makes intuitive sense.

HOW GREEN IS GREEN?

To estimate the hedonic equation, we combined data on land use and "greenness" with housing sales information in a GIS framework. The tax parcel maps for the two counties form the first layer of data. To this we added parcel specific information about housing sales and structural characteristics. The third layer contains maps of federal, state and local or institutional parklands. Finally, the top layer contains data from remote sensing images of the area that are used to define identify "greenness" and categorize the parcels into different categories of land use. Below we describe the data and the variables created for this study in more detail. Table 3 lists all the variables with summary statistics. Below we describe our basic hedonic price function model and the structural and other parcel variables used in the regressions.

Structural and Parcel Variables

Data for housing sales in Orange and Durham Counties, North Carolina, was purchased from TransAmerican Intellitech, a commercially available database of real estate transactions drawn from county records. The database contained nearly 150,000 transactions for residential and commercial properties. For our study, we looked only at residential sales for parcels sold between 1996 and 1998. The final data set contains just over 11,200 observations after trimming the top and bottom 5 percent of sales prices and parcel acreage and deleting observations with missing data. Of these, slightly over 8,300 were located in Durham County and 2,900 were located in Orange County. The data set did not contain a full set of structural variables for most observations, so the structural variables include the number of bedrooms (bedrooms), number of stories (stories), and the year the house was built (yr_blt). In addition, we include the size of the parcel in acres (acres) and acres squared (acres_sq). We estimated the size of the "footprint" of the house on the parcel by multiplying the proportion of the pixels in the parcel that were classified as "developed" by the size of the parcel in acres (dev_lot). Because the dominant land cover in the 30-meter square pixels determines its classification, this should approximate the footprint.

The median lot size of the parcels in our data set was 0.35 acres. The average size of a parcel in Durham County was 0.31 acres, smaller than the average parcel in Orange County, which was just over ½ acres. In addition an acres-squared variable was included to capture the potential for diminishing marginal return of increasing parcel size.

Using the parcel map, we created variables measuring the travel time to employment centers. Traffic analysis zones, provided by the Triangle J Council of Governments, allowed us to determine the three largest employment centers in the two counties: Duke University (located in the City of Durham), Research Triangle Park and University of North Carolina (located in the City of Chapel Hill). Using ArcInfo, we calculated the distance along the road network from each employment center to each parcel using major and secondary highways (Halpin et al., 2000). Anticipated average speeds were varied among the road types with an additional impedance factor added to each route to more accurately represent actual travel time. For locations away from the major road network, the linear distance from the nearest road was determined and added to the travel time. Merging the parcel map and the travel time grid provided an expected travel time from each parcel to each of the three major employment centers. These values created three continuous distance variables: distance to Duke University (duke_dist), distance to the University of North Carolina (unc_dist) and distance to Research Triangle Park (dist_rtp). Figure 3 provides a histogram of the distance from Duke University Hospital in minutes. The Duke University Hospital distance variable initially spikes at just less than 10 minutes with a larger maximum at approximately 20 minutes with a rapid decrease thereafter. Very few parcels are more than 50 minutes from Durham.

Finally we created dummy variables for the municipal boundaries in the area. The municipalities include Durham County (dur_co) and the City of Durham (durcity), which is located in Durham County. In Orange County, we identified properties in the cities of Chapel Hill (chaphill) and Carrboro (carrboro). These boundaries are especially important in Orange County where the Chapel Hill-Carrboro school system is considered to be the highest quality in the two counties. The other municipalities in Durham and Orange are much smaller and contained only a few parcels.

Regression Results

A hedonic price function usually takes a form such as:

$$P=f(Q, N, S) + e \qquad (1)$$

where P is the sales price of the house, Q is a vector of environmental attributes of the house, N is other neighborhood variables such as the quality of local schools, and S is the structural characteristics of the house.[4] The error term, e, reflects uncertainty in the measurement of the variables and in the preferences of the individual homebuyers. With our data, we provide a richer characterization of Q (forest and greenness variables) with which to explore interactions between the elements of Q, as well as the impact of Q on property values.

Using the variables defined above, we estimated several regression models. Simple distance measures mask more complex relationships between parcel greenness, institutional forests, private forest blocks and distance to developed blocks. Table 3 column 2 includes only the distance to an institutional forest, which is typical of much of the prior work in this area. In the third column, we added the variables for mean parcel greenness and the distance to a private forest block. A location closer to both private and institutional forests increases the sales price of

[4] The hedonic price function refers to market equilibrium, which includes the joint decisions of buyers and sellers of houses. Demand for housing, including its various attributes, stem from the contribution of housing and its elements to a buyer's utility function. Values for particular attributes—such as greenness—are reflected in the extra premium a buyer is willing to pay for the particular attribute. These decisions are the outcome of a constrained utility maximization choice for the buyer. See Freeman (1993) for a detailed description of hedonic property theory for non-market valuation.

the house, but the coefficient on distance to an institutional forest is larger. Properties with a higher mean greenness are also more highly valued according to the results in column (3).

Using the mean greenness values (the NDVI values) we created several additional variables to look more carefully at different aspects of greenness. Columns (4) and (5) contain the results from a model that includes several greenness and forest cover variables, respectively using sales price and a Box-Cox transformation of sales price as the dependent variables. The results reveal a more diverse pattern of influence on housing prices. Distance to both institutional and private forest blocks remains negative and significant. Proximity to either type of forest increases the sales price of the house, however the size coefficient on distance to private forest blocks has increased dramatically. Controlling for acres, parcels with a greater proportion of forest cover (prop_for) or sparse vegetation (prop_veg) have greater value, and the coefficient on proportion of the parcel in forest cover is larger than the coefficient on sparse vegetation. However, more acreage of forest or sparse vegetation decreases the value of the parcel. This may reflect a preference for smaller parcels or the distance of the larger parcels from the employment centers.

Being adjacent to a private forest further increases the value of the house. Houses located in and around private forest blocks outside urbanized areas may be more desirable, similar to the "leap-frog" pattern of development observed by Irwin and Bockstael (2000a, 2000b) in the rural area between Washington, D.C., and Baltimore, Maryland. On the other hand, adjacency to an institutional forest block has a negative impact on housing price. Homes adjacent to institutional forests may fetch lower prices if recreational activities in the forest diminish the privacy of the homeowners. Distance to developed blocks has a positive coefficient indicating a higher value for houses that are farther from development.

The two interaction terms, instXgreen and privXgreen, represent a first attempt to capture substitution effects between the various types of greenness a homebuyer may value. InstXgreen is negative and significant. PrivXgreen is positive and significant. Looking first at private forests, the positive coefficient on the interaction term implies greater parcel greenness can compensate for living a greater distance from a private forest block. The negative coefficient on instXgreen is less intuitive. Institutional forests may be complementing parcel greenness in some manner whereby people who like trees choose parcels that have lots of trees and are located close to well recognized institutional forests. It is also possible that the negative coefficient echoes the coefficient on distance to an institutional forest by itself, which is negative. Holding mean greenness constant, properties that are closer to institutional forests are more valuable. Furthermore, the coefficient may also reflect the influence of paired correlation reported in Table 1.[5] Furthermore, distance to private forest blocks has a much stronger negative correlation with the year the house was built than does distance to institutional forests. If the regressions do not properly account for characteristics of the house associated with the age of the house and with

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[5] In this data set mean parcel greenness is slightly positively correlated with distance from an institutional forest and distance from an institutional forest is positively correlated with distance to a developed block.

the neighborhood, which may be associated with distance to institutional or private forests, then the coefficient may reflect these unmeasured factors. While it would be premature to jump to conclusions, the statistical results offer some evidence of how people may be substituting or complementing parcel level, neighborhood and institutional forests in choosing their homes.

In all the regressions, the structural variables, bedrooms, stories and yr_blt, are positive and significant as expected. The size of the parcel, acres, is positive and significant, while acres_sq is negative and significant, indicating that parcel value increases and a decreasing rate as the size of the parcel increases. Our approximate measure of the footprint of the house (dev_lot) is also positive and significant. The dummy variables for living in Chapel Hill and Carrboro, both in Orange County, are positive and significant which matches expectations for the area. Having accounted for the positive impact of living in Chapel Hill or Carrboro, living in Durham County and, within Durham County, living in the city of Durham has a positive impact on property values.

The commuting distance from the parcel to Duke Hospital and RTP (duke_dist and rtp_dist) are positive and significant indicating that parcels located farther from these employment centers are more valuable. While this may seem counterintuitive, RTP contains only business development, no residential development and no commercial development such as grocery stores or entertainment. Many people who work in RTP live south and west of the area in Wake County, which is not included in our study area. Duke Hospital is located near the center of downtown Durham, an area noted for crime. Furthermore, commuting distance to downtown Durham from Chapel Hill is short by the standards of larger cities. Distance from the University of North Carolina (which is located in Chapel Hill) has the expected negative sign.

CONCLUSION

Unlike other environmental variables often included in hedonic price functions, such as local air quality, there is no ambiguity about whether potential homebuyers are aware of trees and forests in the neighborhood. It is well documented that trees on parcels and in neighborhoods provide aesthetic and environmental value. Anecdotally, everyone has observed that the first thing people do in new, clear-cut subdivisions is plant trees.

In this paper, we use several new methods for measuring greenness and local forest cover to explore the interrelationships between similar, but not identical environmental variables related to forest cover and greenness. Future work will extend this analysis in three directions. First we will investigate more formal approaches towards “cross-green” substitution and complementarities between institutional, neighborhood, and personal forests that extend beyond interaction terms. Second we will test the robustness of our findings to different definitions of neighborhood by look at greenness and forest cover in areas of different sizes around the parcels, as well as the greenness of the institutional forests. Finally, we will explore the potential for spatial autocorrelation and spatial lag in our regression equations.[6]

Overall, we find that greenness and forest cover add value to parcels, as does proximity to institutional and private forests. However, while adjacency to private forests seems to add value to houses, adjacency to institutional forests detracted from the value of the parcel. The results of the regressions suggest that parcel greenness can substitute for proximity to private forest blocks and possibly complement proximity to institutional forests.

Previous analyses have tended to focus on public open space or public forests, in part because of the difficulty of obtaining data on private forest blocks. In this paper, we probe beyond open space questions by examining the Research Triangle area, where most of the forest is privately held, and collecting data on private forest blocks. We find that private forests provide an important source of value to houses in the area. In addition, we see that the influence of the institutional forests variable decreased significantly as the other measures of private forest and parcel greenness were added to the specification.

From a policy perspective, the results have implications for land use and conservation efforts. Parcel greenness may provide a substitute for nearness to private forest blocks in the minds of homebuyers, but it does not provide an ecological substitute for large, unbroken tracts of forest. Undeveloped tracts of forest provide public goods to society, but their market value in an undeveloped state is undermined by the willingness and ability of homebuyers to purchase the private, aesthetic benefits of forest cover through greener parcels.

[6]Spatial dependence in the error terms could result from omitted variables that are spatially correlated. Whether this possible correlation would affect the significance of the forest cover and greenness variables is an open question. Acharya and Bennett (2001) did not find evidence of spatial autocorrelation in their hedonic property analysis of the value of open space and diversity of land use patterns.

ACKNOWLEDGEMENTS

We would like to offer our sincere thanks to Lee Mobley for help and advice on spatial errors and lags. This research was supported by a grant from the NSF Urban Research Initiative.

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Table 1. Correlation Coefficients

	mean greenness	prop_for	prop_veg	acre for	acre veg	priv_dist	inst_dist
mean greenness	1.0000						
prop_for	0.6843 0.0000	1.0000					
prop_veg	–0.0155 0.0382	–0.3867 0.0000	1.0000				
acre for	0.1603 0.0000	0.1786 0.0000	–0.0502 0.0000	1.0000			
acre veg	0.0472 0.0000	–0.0037 0.6284	0.1504 0.0000	0.4940 0.0000	1.0000		
priv_dist	–0.1015 0.0000	–0.1213 0.0000	–0.0827 0.0000	–0.1335 0.0000	–0.1235 0.0000	1.0000	
inst_dist	0.0856 0.0000	0.0601 0.0000	0.0966 0.0000	0.1420 0.0000	0.1880 0.0000	–0.0616 0.0000	1.0000
dev_dist	0.2835 0.0000	0.2263 0.0000	0.1358 0.0000	0.1487 0.0000	0.1633 0.0000	–0.3082 0.0000	0.3351 0.0000
inst_adj	0.0482 0.0000	0.0571 0.0000	–0.0212 0.0045	0.1303 0.0000	0.0945 0.0000	–0.0488 0.0000	–0.0613 0.0000
priv_adj	0.2346 0.0000	0.2730 0.0000	–0.0933 0.0000	0.3545 0.0000	0.1592 0.0000	–0.2532 0.0000	0.1565 0.0000
yr_blt	–0.1753 0.0000	–0.0705 0.0000	0.0172 0.0454	–0.0683 0.0000	–0.0557 0.0000	–0.4122 0.0000	–0.0387 0.0000

	dev_dist	inst_adj	priv_adj	yr_blt
dev_dist	1.0000			
inst_adj	0.0017 0.8166	1.0000		
priv_adj	0.2568 0.0000	0.0921 0.0000	1.0000	
yr_blt	0.1783 0.0000	–0.0034 0.6891	0.0064 0.4546	1.0000

Note: significance level of correlation listed underneath correlation coefficient. See Table 2 for definitions of variable names.

Table 2. Summary Statistics

Variable	Description	Mean	Standard Deviation	Min	Max
sales price	Sales Price	135,127.10	68,912.03	18,500.00	360,000.00
inst_dist	Minimum linear distance to nearest institutional forest boundary	2,865.97	2,075.43	0.00	18,540.80
inst_adj	Dummy variable=1 if within 20 meters of an institutional forest	0.00	0.04	0.00	1.00
inst X green	*inst_dist * mean greenness*	1,762.93	1,441.01	0.00	12,000.14
priv_dist	Minimum linear distance to boundary of nearest private forest block of 40 acres or more	771.98	620.51	0.00	2,962.67
priv_adj	Dummy variable=1 if within 20 meters of a private forest block	0.02	0.14	0.00	1.00
priv X green	*priv_dist * mean greenness*	475.06	414.70	0.00	2,524.07
mean greenness	Mean NDVI of 30m x 30m pixels in parcel	0.61	0.16	0.00	0.95
prop_for	Proportion of pixels in the parcel that are categorized “forest”	0.30	0.39	0.00	1.00
acres for	*prop_for * acres*	0.22	0.45	0.00	5.17
prop_veg	Proportion of pixels in the parcel that are categorized “sparse vegetation”	0.31	0.39	0.00	1.00
acres veg	*prop_veg * acres*	0.20	0.38	0.00	4.95
prop_dev	Proportion of pixels in the parcel that are categorized “developed”	0.33	0.43	0.00	1.00
acres dev	*prop_dev * acres*	0.10	0.14	0.00	3.19
bedrooms	Number of bedrooms	3.12	0.73	1.00	11.00
stories	Number of stories	1.12	0.35	1.00	12.00

(continued)

Table 2. Summary Statistics (continued)

Variable	Description	Mean	Standard Deviation	Min	Max
acres	Acreage of parcel	0.55	0.65	0.06	5.28
acres_sq	Acres squared	0.73	2.50	0.00	27.85
yr_blt	Year house was built	1,974.12	22.47	1,822.00	1,997.00
dur_co	Dummy=1 if house in Durham County	0.74	0.44	0.00	1.00
carrboro	Dummy=1 if house in Carrboro	0.03	0.18	0.00	1.00
chaphill	Dummy=1 if house in Chapel Hill	0.09	0.28	0.00	1.00
durcity	Dummy=1 if house in the city of Durham	0.51	0.50	0.00	1.00
duke_dist	Driving time to Duke University Medical Center in Durham	16.68	7.82	1.84	56.28
unc_dist	Driving time to University of North Carolina in Chapel Hill	21.56	9.33	1.18	60.24
rtp_dist	Driving time to Research Triangle Park	18.84	9.30	2.97	66.63
dev_dist	Minimum linear distance to boundary of nearest 10 acre or more developed block	548.76	991.00	0.00	8,293.90
	Numb	11,206			

Table 3. Hedonic Price Functions with Forest Proximity and Greenness Variables, Coefficient and (standard error)

Variable	Sales Price	Sales Price	Sales Price	Box-Cox
inst_dist	-6.03 (0.29)	-5.80 (0.29)	–1.89 (0.86)	–0.01 (0.00)
inst_adj			–23,292.95 (13,315.65)	–96.72 (52.27)
inst X green			–6.21 (1.28)	–0.02 (0.01)
priv_dist		-1.93 (0.94)	–23.29 (3.07)	–0.10 (0.01)
priv_adj			6,293.88 (3,784.07)	26.06 (14.85)
priv X green			35.34 (4.74)	0.15 (0.02)
mean greenness		18,526.15 (3,804.79)		
acres for			–29,037.24 (8,073.14)	–119.77 (31.69)
prop_for			13,448.61 (4,125.37)	52.27 (16.19)
acres veg			–37,529.88 (7,840.51)	–144.20 (30.78)
prop_veg			10,114.29 (4,016.37)	30.91 (15.77)
acres dev		20,117.31 (3,858.00)	2,923.38 (8,947.37)	3.33 (35.12)
prop_dev			3,642.37 (4,142.44)	9.49 (16.26)
bedrooms	24,629.68 (706.07)	24,339.74 (701.66)	24,015.97 (699.20)	87.62 (2.74)

(continued)

Table 3. Hedonic Price Functions with Forest Proximity and Greenness Variables, Coefficient and (standard error) (continued)

Variable	Sales Price	Sales Price	Sales Price	Box-Cox
stories	31638.58 (1695.63)	31,955.34 (1,686.91)	31,905.04 (1,678.81)	104.95 (6.59)
acres	42552.47 (2248.96)	30,087.12 (2,519.55)	583.44 (27.34)	2.68 (0.11)
acres_sq	-7861.91 (524.73)	-5,718.96 (558.66)	57,864.39 (7,603.89)	208.93 (29.85)
yr_blt	595.12 (26.61)	598.95 (27.61)	–5,128.71 (572.97)	–16.54 (2.25)
dur_co	29,690.16 (2582.93)	31,540.88 (2,579.92)	31,421.68 (2,583.42)	124.53 (10.14)
carrboro	18956.33 (3205.98)	21,518.27 (3,200.28)	20,053.49 (3,197.98)	76.62 (12.55)
chaphill	33,254.80 (2312.14)	33,803.71 (2,318.73	32,276.18 (2,315.12)	121.82 (9.09)
durcity	5757.61 (1251.74)	6,339.89 (1,253.00	5,613.03 (1,249.48)	25.59 (4.90)
duke_dist	685.41 (106.78)	605.06 (110.90)	696.85 (110.79)	3.23 (0.43)
unc_dist	-2621.62 (97.06)	-2,834.28 (99.44)	–2,821.09 (100.36)	–10.64 (0.39)
rtp_dist	1628.11 (111.00)	1,406.04 (111.70)	1,411.61 (111.82)	5.31 (0.44)
dev_dist		8.11 (0.73)	8.27 (0.73)	0.03 (0.00)
cons	-1,167,144 (51122.02)	-1,176,933.00 (53,945.67)	–1,144,523.00 (53,023.99)	–4,793.50 (208.15)
R^2	0.47	0.48	0.49	0.48
# obs	11,206	11,206	11,206	11,206

Figure 1. Research Triangle Region: Forest Patches >40 Acres

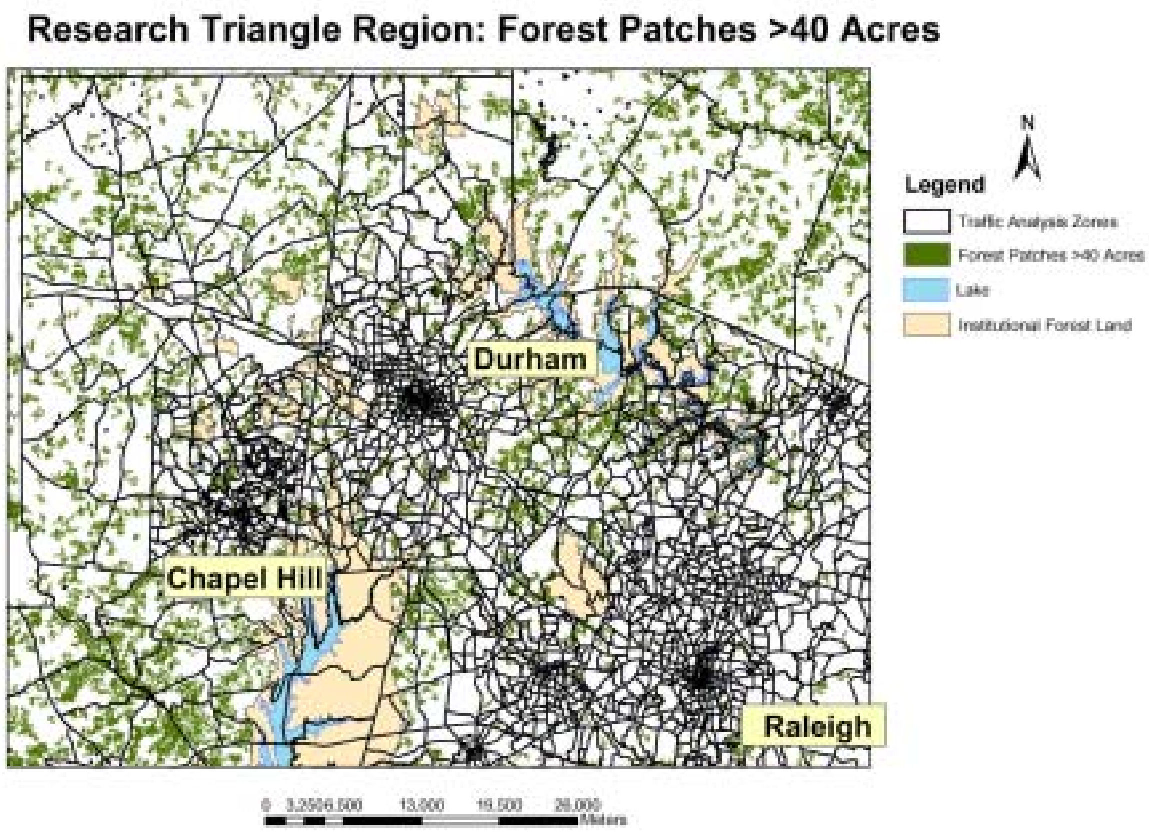

Figure 2. Research Triangle Region: Developed Areas >10 Acres

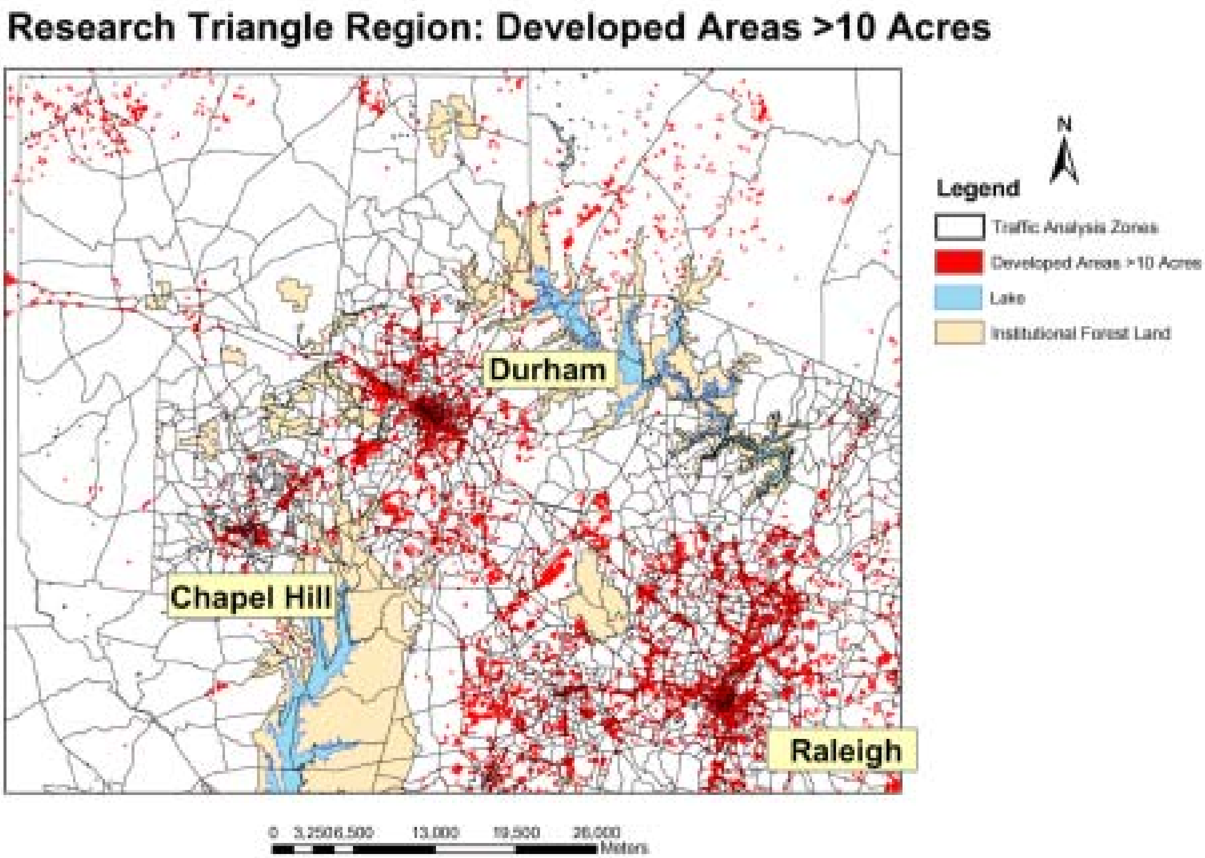

Figure 3. Parcel Distribution of Distance from Durham, in Minutes