Valuing the Benefits of the Urban Forest: A Spatial Hedonic Approach

Seth Payton*
Center for Urban Policy and the Environment
Indiana University-Purdue University Indianapolis

Greg Lindsey
Center for Urban Policy and the Environment
Indiana University-Purdue University Indianapolis

Jeff Wilson
Department of Geography
Indiana University-Purdue University Indianapolis

John R. Ottensmann
Center for Urban Policy and the Environment
Indiana University-Purdue University Indianapolis

Joyce Man
School of Public and Environmental Affairs
Indiana University, Bloomington

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*Corresponding author:
Email: sbpayton@iupui.edu
Center for Urban Policy and the Environment
Indiana University-Purdue University Indianapolis
342 N. Senate Avenue, 3rd Floor
Indianapolis, Indiana 46204-1708

ABSTRACT. This paper measures the benefits of the urban forest by examining its effect on housing prices. A Geographic Information System is used to develop a measure of the urban forest, the Normalized Difference Vegetation Index, from satellite imagery and to construct other variables from a variety of sources. Spatial hedonic housing price models for the Indianapolis/Marion County area are estimated. The models indicate that greener vegetation around a property has a positive, significant effect on housing price, holding everything else constant. This effect is dominated by measures at the neighborhood level. These findings indicate that property owners value the urban forest, at least in part, by the premium they pay to live in neighborhoods with greener, denser vegetation. These findings also indicate that public action to maintain and enhance the urban forest may be warranted. Planners and urban foresters can use these findings to inform public and policy debates over urban forestry programs and proposals.

INTRODUCTION

Do urban residents care about the health of the environment around them? Do urban residents care if their neighborhood is "green"? If they do, how much do they care? Is public intervention to maintain the urban forest warranted? These questions have important implications as debates that are decades old continue about urban form, open space, and "preservation of land in a natural, garden-like, or agrarian state" (Correll et.al. 1978).

Practitioners and academic scholars are increasingly citing the importance of forests in America. They are not wholly focusing their attention on national preserves or rural areas. Defining urban forest as all vegetation in an urban area, many have described the environmental benefits of the "forest" in densely populated urban areas (Miller, 1998). If not explicitly stated, it is implied that enhancing urban forests warrants public intervention (Herzog 1989, Heynen & Lindsey 2003, Jackson 2003, Miller 1998, McPherson et.al. 1997; Swaffield & Fairweather 1996; Tryvainen & Hannu 1998; Wolf 2004; Kestens et.al. 2004). Although this evidence indicates that public investment in urban forests may be warranted, policy-makers may find it difficult to justify allocation of public resources for public programs when they lack evidence of economic benefits expressed in monetary terms. As competition for scarce public resources escalates, the pressure to demonstrate economic values commensurate with those associated with investments in schools, roads, water systems, police, and sports facilities will increase. It, therefore, is important to examine and illustrate the economic or monetary values of urban forests.

The primary focus of this paper is to identify how urban property owners value greener vegetation at two geographic scales; the property level and the neighborhood level. A hedonic model using contemporary spatial econometrics is estimated using residential real estate sales prices as a proxy for value and the Normalized Difference Vegetation Index (NDVI) as a continuous measure of variation in green vegetation. Defining urban forest as "everything green," we use NDVI as a proxy for the extent and vigor of the surrounding urban forest. Our analyses show that the effect of greener vegetation surrounding a property has a positive effect on price. The magnitude of the positive effect, however, is determined by the level of greenness at a broader, neighborhood-level. Private investment in a "greener" property is diminished if there is not a comparable investment in the neighborhood. Inferences that follow from this finding are that urban forestry is a public or collective concern and that, to at least some extent depending on costs, public forestry programs, including tree planting and maintenance, may be warranted.

This study complements other, similar analyses and contributes to the literature in several ways. First, it focuses on two levels of geography (the residential property and its immediate environs and its neighborhood) to understand the extent of the relationship of greener urban forest on housing values and how the public values the urban forest. Next, it makes use of contemporary spatial econometric techniques to estimate that relationship. Finally, it is one of a few known uses of NDVI as a continuous comprehensive measure of greenness in urban forest valuation.

The remaining sections of this paper provide a review of relevant literature on valuing the urban forest, the conceptual framework and methods used, estimates for the effect of "greenness" on housing prices in an urban area, and annualized willingness to pay values in that urban area. The analysis is a case study of Marion County (Indianapolis), Indiana. The paper concludes with a discussion of the implications of this research.

THE VALUE OF A GREENER URBAN ENVIRONMENT

The United States Department of Agriculture's Forest Service makes a direct linkage between urban forests (defined as all associated vegetation in and around dense human settlement) and quality of life in the mission of its Urban and Community Forest Program (USDA 2007; Miller, 1998). That linkage has been consistently supported by empirical analyses. In a review of urban forestry literature, Heynen and Lindsey (2003) found that researchers have reported that greener urban landscapes are not only beneficial in moderating temperature, improving air quality, controlling runoff and flooding, reducing noise levels and causing residents to become more emotionally attached to their communities, but that they also increase property values.

Decades of research efforts linking environmental amenities and housing prices have been forged not only in the subfield of environmental and land economics (Correll et.al. 1978, Morales 1980, Tryvainen and Miettinen 2000, Geoghegan 2002, Irwin 2002, Kestens et. al 2004, Lindsey et. al 2004, Mansfield 2005), but also in fields such as real estate finance and economics (Do and Grudnitski 1995, Benson et al. 1998, Segerson 2001). Several of those studies focus on the impact of trees, nearby open space, or zoning on property values. While measurement techniques have varied, most studies have imputed the impacts on property values by extrapolating from detained analyses of particular properties or from hedonic price analyses.

Researchers generally have found that trees and open space have a positive significant effect on property values and that the effect of nearby open space or parks diminishes as distance to a property increases (Payne and Strom 1975; Morales, 1980; Anderson and Cordell, 1985, 1988; Schroeder, 1989; Tyrvanien and Miettinen, 2000, Irwin, 2002, Mansfield et.al. 2005). These studies complement others, which have found that certain types of open space and urban, nature-related developments (e.g. public parks and greenways) can increase quality of life through positive effects on resident health and the environment (Little

1990, Flink et.al. 1993, Smith and Hellmund 1993, Fabos & Ahearn 1996, Moore & Schafer 2001, Geoghegan 2002,Heynen & Lindsey 2003, Lindsey 2003, and Lindsey et.al. 2004).

This study uses an approach similar to two recent studies in so far as it incorporates the Normalized Difference Vegetation Index (NDVI) as a measure of greenness on or near a property rather than distance to nearest forest or open space (Kenston et.al. 2004, Mansfield 2005, Netusil 2005). Similar to those studies, the NDVI is justified as a measure for the extent and health of urban forest. While a blunt measure of everything green, NDVI is a relatively simple measure to calculate, it fits most notions that urban forests include more than just trees, and the scale at which the data are collected allows for localized analyses.[1]

This study differs from previous studies because it uses NDVI for the neighborhood around the property as well as for the property itself. The NDVI measures are not classified, but used as a continuous variable. That measure also is not constrained by administrative boundaries (e.g. parcels), but is constructed around uniform radii around each observation. Consistent with previous research, we hypothesize that greener neighborhoods increases property values. We extend previous findings by estimating the effects at two geographic scales and by calculating aggregated annualized values. This study also addresses a limitation of previous studies by using a spatial lag regressor in the estimation process to adjust for spatial autocorrelation—a problem that is inherent in spatial data like property values.

THE HEDONIC APPROACH

The hedonic price method estimates the implicit price of various housing unit and neighborhood characteristics (Rosen 1974). The housing market can be used in these models to calculate and isolate an implicit value for intangibles that are not explicitly valued in the market, like green vegetation (Haab and McConnell, 2002). Ordinary least squares (OLS) regression is the most common method for hedonic modeling. However, traditional OLS does not account for spatial autocorrelation, a troubling complexity of spatial data associated with the simultaneous influence on the price of each observation by the price of nearby observations. Because spatial autocorrelation technically violates the assumption of case independence, it may result in biased regression estimates. Specifically, if spatial autocorrelation exists in the data and is not mitigated, it is possible that the resulting estimates will be inefficient and inconsistent (Anselin 1988, Anselin and Bera 1998).

Rectifying the spatial dependence problem in a spatial data set can be accomplished in several ways (Kim, Phipps, and Anselin 2003, Fotheringham et.al. 2000; Anselin & Getis 1992; Can 1990; Anselin 1988, Dubin 1988, Odland 1988). Spatial lag models are used here based on conceptual reasoning. House listing prices are at least partially determined based on the sale price of spatially immediate properties, or comparables. The spatial lag model addresses the potential spatial interaction between the dependent variable (house price) of each observation and its neighbors (Anselin & Getis 1992). These spatial lag models are operationalized through maximum likelihood (ML) estimation and so called spatial two-stage least squares (S-2LS; Kelejian and Prucha 1999).

The theory of hedonic modeling is based on the concept that housing prices are divided between housing characteristics and location attributes. Formally, the specification of the base OLS model is as follows:

$$(1) \quad p = \beta_0 + \sum \beta_k S_k + \sum \beta_j L_j + u$$

where:
p= a vector of housing prices
Sk= a matrix of structural characteristics
Lj= a matrix of location characteristics
$\beta_{0,}$ $\beta_{k,}$ and βj = corresponding parameters
u= vector of random errors

The spatial lag model includes a price weight matrix of neighboring observations.

$$(2) \quad p = \beta_0 + \rho Wp + \sum \beta_k S_k + \sum \beta_j L_j + u$$

Where:

p= a vector of housing prices

W= spatially lagged weight matrix

ρ= corresponding parameters

Following the lead of most hedonic models in the literature, this study uses the natural log of sale price as the dependent variable.[2] There is little theoretical guidance as to which characteristics and attributes to include. The house unit variables in these models commonly include attributes such as total square footage, number of stories, and age of housing unit. Common location attributes include neighborhood variables such as racial composition, neighborhood median income, and accessibility to employment.

Constructing the weight matrix for the spatial lag variable is an additional complexity when using the spatial lag models (Anselin and Bera 1998). For the purposes of this study, various definitions were tested, ranging from contiguous properties to distance thresholds as large as a two-mile radius around each observation. [3] A one-mile threshold radius was ultimately chosen in for our models. [4]

DATA AND MODELS

This analysis makes use of data from several sources. All variables in the model are listed, described, and cited in Table 1. The study area is Indianapolis/Marion County, Indiana. The data set is based on units sold in Marion County during 2004. Each unit sold was merged with location characteristics through the use of a geographic information system (GIS).

[TABLE 1 ABOUT HERE]

The housing sales data used in this analysis were extracted from the Multiple Listing Service (MLS) database maintained by the Metropolitan of Indianapolis Board of Realtors (MIBOR). MIBOR estimates that roughly 80 percent of all sales in their service region are included in the MLS. The variables extracted from the MLS system include address, year built, sale date, number of rooms, number of bedrooms, square footage, garage type, porch type, lot size, cooling system, exterior type, number of stories, and semi-annual tax amount. Because multiple parties enter these data, extensive data cleaning was necessary. Outliers and cases that did not contain enough information to be included in the model were dropped from the dataset. The final data set used for this analysis included 9, 716 cases.

The focus of this report is on location variables that measure the greenness of urban vegetation at different geographic scales. Measurements of urban vegetation were derived from satellite imagery acquired over the study area by the Landsat 5 remote sensing system on June 6, 2004. That system collects imagery at a spatial resolution of 30 meters. NDVI values were calculated from red and near infrared (NIR) reflectance using the formula NDVI = (NIR – Red) / (NIR + Red) (Tucker, 1979). The NDVI is a well established method for estimating vegetation parameters via remote sensing imagery and has been documented as a positive correlate of biophysical plant characteristics including percent vegetated ground cover (Gamon et al., 1995) and net primary productivity (NPP) in grassland and forest ecosystems (Paruelo et al., 1997; Chen and Brutsaert , 1998; Wang et al., 2003).

Three basic models were constructed to examine the effect of the urban forest on housing prices. The first model (Model 1) includes all relevant housing unit and neighborhood characteristics, plus the average (30m x 30m pixel) NDVI for 2-acres surrounding each housing unit in the sample (See Figure 1).[5] The second model excludes the measure at the 2-acre scale and adds a measure at the 11-acre scale. The third model considers both geographic scales together. Specifically, it measures jointly the effect at the 2-acre (property) scale and the effect of a nine acre "donut" computed as the difference between the remaining neighborhood (within the 11 acre neighborhood) and the immediate 2-acre area.

Each of the models can be summarized as follows (see Figure 1 for graphic representation):

$$(3)\quad \log(sprice) = \beta(constant) + \beta(NDVI\_2acre) + \mathbf{x}\partial + u$$

$$(4)\quad \log(sprice) = \beta(constant) + \beta(NDVI\_11acre) + \mathbf{x}\partial + u$$

(5) log(sprice)= β(constant) + β(NDVI_2acre) + β(NDVI_Difference) + **x∂** + u

Where:

Log(sprice)= Vector of the log of house price

NDVI_2acre=a vector of average 30 x 30 meter pixel NDVI at 2-acre scale

NDVI_11acre=a vector of average 30 x 30 meter pixel NDVI value at 11-acre scale

NDVI_Difference=a vector of average 30 x 30 meter pixel NDVI value difference between within area of 11_acre NDVI (but outside 2_acre area) and NDIV_2acre

x∂=Matrix of Housing Unit and Location Characteristics

β= corresponding parameters

u=vector of errors

[FIGURE 1 ABOUT HERE]

Each NDVI measure is the average of 30m x 30m pixels within its respective area. A two acre area is used for the individual property because of the distribution of residential lot sizes in Marion County. Two acres is inclusive of most properties in the database; an individual pixel (0.22-acre) would not be large enough to cover all properties. Descriptive statistics indicate that 12 percent of all observations in our sample are located on lots greater than 0.5 acres, which is double the area of the individual pixels. Each of the models was first run with the more commonly used OLS specification. Then, the same models are estimated using spatial lag specifications.

The NDVI measure was rescaled for ease of interpretation. First, the values were multiplied by 100. Next, the value of 100 was added to the NDVI value. This rescaling results in a range of values in Marion County from 70 to 170 across all 9,716 observations. The average NDVI at the two-acre scale for the observations in this data set is 138.5884 and a standard deviation of 13.5591. The average NDVI at the 11-acres scale is 138.9031 and a standard deviation of 11.4502. The NDVI_difference variable (difference between the remainder of the 11-acre and 2 acre) average was 0.38 with a standard deviation of 6.8716.

Other variables used in the analysis came from public sources. All data collected from the US Bureau of the Census were collected at the block group geographic level. The housing data were joined with those data based on the Census block group in which each observation is located. Mean Indiana Statewide Testing for Educational Progress (ISTEP) standardized test scores by school district were used as a measure of school performance. Each observation was assigned an ISTEP value based on the school district in which it is located. Four location based binary variables are included in the model based upon local knowledge of the housing market and an analysis of residuals in previous models. All observations are coded based on whether or not they are located in Center Township, the Downtown/Lockerbie area, the Meridian-Kessler/Broad Ripple Area, and the Near Westside area.[6] Table 2 shows the mean and standard deviation for all of the variables included in the model.

[TABLE 2 ABOUT HERE]

RESULTS

Table 3 shows the OLS results for each of the three models explained in Equations 2-4. All models explain more than 87 percent of the variance in housing prices. All estimated coefficients are significant at $p<0.01$ and have the expected sign. Since the models are log-level (the dependent variable [Price] is in log form while the independent variables are level), the coefficients may be multiplied by 100 to represent percent change in price for each one unit increase in each independent variable. Model 1 indicates that greater NDVI values have a significant positive effect on residential sale price. Specifically, the model shows that a one unit change in average NDVI at the 2-acre scale leads to a 0.12 percent difference in sale price. The effect of average NDVI at a broader neighborhood level (Model 2), roughly 11-acres surrounding each property, also is positive and significant. The magnitude of the effect associated with the 11_Acre NDVI coefficient is somewhat larger than the magnitude of the effect of the 2_Acre NDVI coefficient. A one unit difference in NDVI at the 11-acre scale represents a 0.17 percent change in housing price.

Neither Model 1 nor Model 2 provides evidence to determine the effect at the 2_ACRE scale in context of the 11-acre surroundings. Model 3 seeks to separate the effects of those scales by including both measures in the same model. That is, combining the 2-acre NDVI with the difference of the 11-acre NDVI surrounding the 2-acre area allows for understanding the relationship of the surrounding vegetative health on each property, controlling for the health of the immediate vegetation surrounding the property. That model indicates that the relationship between the two scales is important. First, the 2-acre NDVI is positive and significant, suggesting that a greater NDVI (the greener the area) is related to higher house prices. However, the effect at that narrower geographic scale and the 11acre scale cannot be considered separately.

The meaningful estimate for the effect of one unit change in NDVI at the 2_ACRE scale is $\beta_{NDVI\text{-}2acre} + \beta_{NDVIdifference}$. If 2_Acre NDVI is increased by one unit above the average and the surrounding area within the 11-acre area is not increased, the effect is calculated by summing $\beta_{NDVI\text{-}2acre}(1) + \beta_{NDVIdiffernce}(-1)$. The result is 0.01 percent.

6)	Effect of One unit change in 2-acre NDVI with no Change in Surrounding area	$=\beta_{NDVI\text{-}2acre}(1) + \beta_{NDVIdifference}(-1)$
	Effect of One unit change in 2-acre NDVI with no Change in Surrounding area	$=0.0018(1) + 0.0017(-1)$
	Effect of One unit change in 2-acre NDVI with no Change in Surrounding area	$= 0.0001$

However, if the both areas increase simultaneously ($\beta_{NDVI\text{-}2acre}(1) + \beta_{NDVIdifference}(0)$), the effect on price is 0.0018. Likewise, if there is no change in the 2-acre NDVI and the NDVI of the surrounding area is increased by one unit ($\beta_{NDVI\text{-}2acre}(0) + \beta_{NDVIdifference}(1)$) the result is a 0.0017 increase in price. Model 3 illustrates the importance of neighborhood context when considering NDVI values. Higher NDVI values (greener surroundings) are related to higher economic values. However, according to the preliminary OLS models, the value of increased NDVI levels in the immediate area is dependent upon its context within the broader 11-acre area.

[TABLE 3 ABOUT HERE]

The results from the OLS models provide a general frame of reference for understanding the effect of the urban forest and other housing unit and location attributes, but they could be biased and inconsistent estimates due to the spatial nature of the data. The spatial dependence diagnostics from the traditional OLS model to evaluate spatial autocorrelation, including robust and non-robust forms of the Lagrange Multiplier (LM), were significant and justify the use of the more complex spatial lag models (Anselin 2005). The non-robust and robust forms of the Lagrange Multiplier (LM) lag and LM error statistics are significant.

Table 4 shows the coefficients for the spatial lag models. The spatial lag coefficient is significant in all models and indicates that roughly 36 to 37percent of the variance explained by the models are already represented in the value of neighboring houses. The largest change is in neighborhood location variables. That is expected because the inclusion of the spatial lag is mitigating the spatial autocorrelation of those variables. The ML and S-2LS coefficients are comparable, varying only slightly between some variables. The urban forest density measures in both model types (ML and S-2LS) are identical. The only variables that do not maintain significance at the $P<0.01$ level are the Near Westside location binary variable (significant at $P<0.05$) and the NDVI difference variable. However, the NDVI difference variable is considered jointly with 2-acre NDVI in Model 3. That variable is jointly significant with the 2-acre variable. The relative nature of property and neighborhood vegetation remains the same. The effect of increased

NDVI levels at the 2-acre scale is diminished if there is not a corresponding change at the broader 11-acre scale.

[TABLE 4 ABOUT HERE]

The interpretation of the spatial lag model is somewhat more complex than the traditional OLS approach. Technically, the spatial lag model involves the estimation of both direct and induced effects. The reported coefficient for each variable is the direct effect. The spatial lag coefficient serves as a multiplier for the induced effect. That multiplier is included in the effect of vegetation by multiplying the vegetation coefficient by $1/(1-\rho W)$; where ρW is the parameter of the lag variable. The resulting multiplier from the 0.36 lag coefficient in all 2-SLS Models is 1.56, for an induced effect of 56 percent. The resulting multiplier for the MLE models is 1.59, for an induced effect of 59 percent.

Because the Breusch-Pagan test for heteroskedasticity was significant at the $p<0.01$ level, the 2-SLS robust model is used to examine the effect of the urban forest. The total premiums calculated by incorporating the multiplier to the direct effect of 2acre NDVI in Model 1 (0.0007) and the 11acre NDVI in Model 2 (0.0009) are 0.0011 and 0.0014, respectively. Those values are slightly lower than the coefficients from the traditional OLS model. That indicates the effect of NDVI and other variables is already partially contained in the price of surrounding homes. Figure 2 shows the distribution of units by 11-acre NDVI and the direct effect and total effects on the average housing price. In effect, the figure represents the change in price on the average house if it was moved along the spectrum of NDVI values.

[FIGURE 2 ABOUT HERE]

The difference between the average NDVI and the property with the lowest NDVI is 59 units, or a 74 percent decrease. The price of the average house if moved from the average NDVI to the lowest NDVI would decrease by over $7,000, or 8 percent holding everything else constant. The highest 11-acre NDVI was 32 units greater than the average. The effect on the average home moving from the average 11-acre NDVI to the highest 11-acre NDVI observed is a premium of approximately $3,000, or about 4 percent holding everything else constant.

Calculating the effect the NDVI measures in Model 3 of the spatial lag models similar to the way they were calculated for OLS model, a one unit increase at both geographic levels has a direct effect of increasing property values by approximately 0.09 percent. The total effect, including the 1.57 multiplier using the spatial lag coefficient, is 0.14 percent. Generally, all models indicate that greener areas of an urban space add value to properties. The price premium on the average property from the evenly distributed one percent increase in 11-acre NDVI is $163.[7] A 10 percent increase results in a $1,633 price premium on the average property.

Analysis of both NDVI variables in Model 3 provides valuable insight into the effect of urban forest on the immediate vicinity of a property within the context of a broader 11-acre area. The direct effect of a one percent (1.38 units) increase in average 2-acre NDVI with no change in the remaining area of the 11-acre neighborhood is the equivalent to:

6) Effect of one percent change in 2-acre NDVI with no change in surrounding area $=\beta_{NDVI\text{-}2acre}(1.38) + \beta_{NDVIdifference}(-1.38)$

Effect of one percent change in 2-acre NDVI with no change in surrounding area $= 0.0009(1.38) + 0.0007(-1.38)$

Effect of one percent change in 2-acre NDVI with no change in surrounding area $= 0.0002$

Where $\beta_{NDVI\text{-}2acre}$ is the coefficient of the average 2-acre NDVI variable, $\beta_{NDVI\text{-}11acre}$ is the coefficient of the average NDVI variable, and 1.38 is the amount of a 1 percent increase in the average 2-acre variable. As shown, a one percent increase in average 2-acre NDVI with no change in the remaining area of the 11-acres increases the value by 0.02 percent. That is equivalent to an increase of a $20 direct effect on average price. The total effect can be found by multiplying the spatial multiplier (1.56) by 0.0002. The result is a total effect of 0.0003, which amounts to a 0.3 percent increase, or $26.30. A 10 percent increase in the immediate vicinity (2-acre scale) with no change in the surrounding area increases the housing price paid by $263.

As shown, the values associated with an increase in the 2-acre NDVI without a similar change in the surrounding area only increases the value by a fraction of the amount that would occur if the entire 11-acre area increased at the same level. In fact, increasing the value on the immediate property by one percent on the average house has a total effect of $26.30 while an increase in the entire 11-acre yields $163. Therefore, the immediate property owners only receive 16 percent of the return on their investment without the equivalent change in the surrounding neighborhood.

From another perspective, if a property owner and immediate neighbors (within a 2-acre area) maintain the state of the vegetation at the 2-acre scale, but the amount and health of vegetation in the surrounding area increases by one percent, the resulting direct effect is 0.0009(0) + 0.0007(1.38), or 0.10 percent (or $81.42 on the average house). The total effect using the spatial multiplier is a 0.15 percent, or $127 increase. A 10 percent increase of the surrounding area above the immediate 2-acre area of the average house leads to a total effect of 1.5 percent, or $1,270 increase. Likewise, if property owners and their immediate neighbors within the 2-acre scale maintain their property vegetation and the surrounding properties' vegetation within the remainder of the 11-acre area decreases by 1 percent to 10 percent, the result will be a price discount of $127 to $1,270 at the 2-acre scale.

From the scenarios presented, a greener environment is clearly valued at a macro scale. However, at a micro level, there is a disincentive associated with being the greenest property in the area. There is a paradox, whereby the goal in obtaining maximum return on private investment from the benefits of a greener space (measured by increased housing values) is heavily reliant upon the investment decisions of neighbors at a broader scale. In context, all households receive the greatest return on their private investment with an equal increase in, or maintenance of, health and density of the vegetation across the study area.

ANNUALIZED AVERAGE WILLINGNESS TO PAY FOR GREEN

The constructed hedonic price equation can be used to calculate the annualized average willingness to pay for a permanent increase in NDVI across for the entire study area, Marion County (sample is 2004). The values must be annualized to measure household willingness to pay on an annual basis.[8] The 11acre NDVI coefficient (Model 2) is used to calculate willingness to pay because reported evidence indicates that the urban forest at least affects housing values up to 11-acres from a subject property.

Three discount rates are used due to the sensitivity of rate choice. A four percent rate is the lowest, six percent is used as a middle range, and eight percent is used as a high discount rate. The expected life of structures for residential household use is 30 years, based on standard mortgage length.

While point estimates (coefficients) are reasonable approximations of attribute effects on house price in a hedonic model, standard errors are used to account for sensitivity of those values. Model 2 (S-2LS) estimates a 0.0009 house price change for each one unit change in the average 11acre NDVI with a robust standard error of +/-0.0003. Thus, the standard error is between 0.0006 (lower bound) and .0012 (upper bound). Those values and the spatial multiplier were used to calculate the marginal willingness to pay for a permanent one percent increase in NDVI at each discount rate for the sample.

Table 5 illustrates that the average marginal willingness to pay is highly sensitive to the discount rate used to annualize the estimates. For example, the lower bound estimate of the average marginal willingness to pay for a permanent one percent county-wide increase in NDVI is $46 when a four percent discount rate is assumed. An eight percent discount rate for the same increase in NDVI yields a lower bound average of $15. It is difficult to know the optimal discount rate. Therefore, it is reasonable to focus on the six percent rate as a compromise between two extremes.

Based on our estimates, the average household is willing to pay between $26 and $52 annually for a one percent increase in neighborhood NDVI. Conservatively, those values also are estimates for how much the average household is willing to pay to ensure that the extent and health of vegetation does not decline. The aggregate value for a one percent increase in neighborhood NDVI can be calculated if it is assumed that the housing market is in equilibrium and sample values hold for all 208,957 owner occupied units in Marion County.[9] That value is between $5.4 million and $10.8 million using a six percent discount rate.

[TABLE 5 ABOUT HERE]

DISCUSSION AND IMPLICATIONS

Urban form, land use, and development patterns all influence the physical structure of the landscape, how it functions, and how it is perceived (George and McKinley 1974, Nowak et.al. 1994, Burchell et.al. 1998, Burchell et.al 2000, Wolf 2004). Physically, for example, human settlement can change storm water run-off and emissions from automobile use can affect air quality, both of which can indirectly have negative impacts on the health of vegetation. These physical changes may have negative effects on the surroundings as well as change the perceived quality of life of households residing in a “grayer” rather than “greener” environment. Non-profit organizations and all levels of government base policy decisions on these presumed rationales.

National non-profit organizations like American Forests and The National Arbor Foundation promote programmatic standards and goals for tree canopy preservation, citing as rationale the economic value of trees in urban areas (http://www.americanforests.org/;http://www.arborday.org/). As the primary governmental overseer of national urban forest policy, the USDA Forest Service distributes federal grants to state governments on a competitive basis. State governments are encouraged to develop policies, market and communicate services, and perform research with a national significance and impact to obtain funds (Wolf 2003). Preferences also are given to states with "Tree Cities." Tree Cities are designated based on a city's ability to attain a specific set of programmatic standards (http://www.arborday.org/programs/TreeCityStandards.cfm). Hundreds of municipalities have sought Tree City status; many others operate urban forestry and tree planting programs.

At the local level, some municipalities have developed plans, rules and regulations, and policies to manage the urban forest. Municipalities influence the urban forest by planting and maintaining trees on public lands and regulating the location, density, and nature of development, most often through zoning ordinances or subdivision regulations. Some municipalities require that developers plant trees in new developments. In some communities, tree ordinances provide guidance for planting, maintaining, and removing trees from streets, parks, and other public spaces (Grey 1996; Miller 1997).

The study here compliments and builds upon the decades of scholar research that supports the establishment of policies to invest time, space, and money into projects such as greenbelts, urban tree programs and standards, and the creation of parks. It adds to the economic justification for continued resource allocation to urban foresters and local ordinances to balance certain types of development and preserve vegetation. The results from our study indicate that urban officials may provide a disservice that has financial implications for property owners if they do not monitor and remediate damaging changes to community vegetation.

Even after controlling for the spatial interaction of housing prices, we find that households pay a premium for homes located in neighborhoods with greener, denser, vegetation. That analysis also shows that the premium is dominated by greenness beyond the immediate vicinity of average residential property. The fact that residents more heavily value an amenity that is not within their private control has important public policy and planning implications.

In his book, *The Public and Its Problem*, John Dewey defined public as, "… all of those who are affected by the indirect consequences of transactions to such an extent that it is deemed necessary to have those consequences systematically cared for" (1927, pg 15). In short, he created a definition of public to assist in determining when public action is triggered. In the case of urban forestry, public action is triggered by residents valuing the neighborhood vegetation at a greater magnitude beyond their immediate vicinity. Following Dewey's framework, public intervention is warranted for urban forestry. That intervention is valued at roughly the premium paid to avoid a loss or to gain an increase in the value of a resident's property investment.

The analysis indicates that Marion County households are willing to pay between $15 and $92 annually for a permanent one percent county-wide increase in denser, healthier urban forests. The total value is between $3.1 million and $19.2 million if those values hold for the entire owner occupied housing stock. While this is a case study of one urban area, it is a typical urbanized area with types of development that potentially compromise the preservation of the urban forest. It serves as an example of how urban residents value denser, healthier forest areas.

Planners and policymakers can use these findings in a wide variety of practical situations. They provide justification for municipal goals for tree canopy cover, development-related tree planting requirements, urban forestry programs, and ecologically-based principles for planning and design. Strategies that may be warranted include design standards, ordinances and regulations with a focus on urban forest maintenance and tree planting programs in older developed areas. The results of this study and others like it also may be used to educate the general public about the various investments they make to the their property and how the health of the urban forest plays a critical role.

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TABLES & FIGURES

Table 1. Variables included in analysis (N = 9,716)

DEPENDENT VARIABLE	UNITS/NOTES	SOURCE (YEAR)
Sale price (log)	Log Sale Price	MIBOR (2004)
INDEPENDENT VARIABLE	UNITS/NOTES	SOURCE (YEAR)
Urban Forest Variables (3)		
2_Acre NDVI	Average NDVI value for nine pixels in which property is located (2acres)	Department of Geography – IUPUI
11_Acre NDVI	Average NDVI value for pixels in 11 acre area including each property	Department of Geography - IUPUI)
NDVI_Difference	Difference between average NDVI value for pixels in 9 acre donut and 2 acre property area	Department of Geography – IUPUI
Neighborhood Variables (10)		
Mile Density	Estimated number of structures with fewer than two units, based on Census block group	Census 2000
Effective tax rate	Annual taxes divided by sales price	MIBOR (2004)
ISTEP	Mean Indiana Statewide Testing for Educational Progress standardized test scores in school district; indicator of school quality	Indiana Department Of Education (2004)
Median neighborhood household income	Neighborhood defined as census block group	Census 2000
Center Township location	Value = 1 if in Center Township, 0 otherwise	Census 2000 Tiger files
Percentage non-White Population	Neighborhood defined as census block group	Census 2000
Accessibility to employment	Measured as sum of zip code employment weighted by the negative exponential of distance to the zip code	Census Zip Business
Meridian Kessler/Broad Ripple Area	Value = 1 if in Approximate Meridian Kessler/Broad Ripple Area, 0 otherwise	Center for Urban Policy and the Environment
Downtown/Lockerbie Area	Value = 1 if in Approximate Downtown/Lockerbie Area, 0 otherwise	Center for Urban Policy and the Environment
Near Westside Area	Value = 1 if in Approximate Near Westside Area, 0 otherwise	Center for Urban Policy and the Environment
Housing Attribute Variables (10)		
Square feet	Total Square Feet in House (In Hundreds)	MIBOR (2004)
No air conditioning	Value = 1 if no cooling, 0 if air conditioning	MIBOR (2004)
Number of Bathrooms	Total Bathrooms	MIBOR (2004)
Age	Years	MIBOR (2004)
Number of rooms	Number of rooms in house	MIBOR (2004)
Lot less than ½ acre	Value = 1 if lot is less than 1/2 acre, 0 otherwise	MIBOR (2004)
Lot more than 1 acre	Value = 1 if lot greater then 1 acre, 0 otherwise	MIBOR (2004)
Brick facing	Value = 1 if brick facing, 0 otherwise	MIBOR (2004)
Porch	Value = 1 if porch or deck or both, 0 otherwise	MIBOR (2004)
Garage Bays	Number of attached and/or detached garage bays	MIBOR (2004)

TABLE 2: DISCRIPTIVES OF VARIABLES		
DEPENDENT VARIABLE	AVERAGE VALUE	STANDARD DEVIATION
Sale price (log)	11.34	0.84
INDEPENDENT VARIABLE	AVERAGE VALUE	STANDARD DEVIATION
2_acre NDVI	138.59	13.56
11_acre NDVI	138.90	11.45
NDVI_Difference	0.39	6.87
Mile Density	3281.338	1628.544
Effective tax rate	1.67	1.60
ISTEP scores	963.0441	38.13
Median neighborhood household income	$48,296.23	$21,029.26
Center Township location	0.17	0.38
Percentage non-White Population	27.27	28.57
Accessibility to employment	104124.6	33273.35
Meridian Kessler/Broad Ripple Area	0.05	0.22
Downtown/Lockerbie Area	0.01	0.12
Near Westside Area	0.03	0.16
Square feet (100)	19.41	9.52
No air conditioning	0.19	0.39
Number of bathrooms	2.00	0.90
Age	43.57	29.38
Number of rooms	7.12	2.01
Lot less than ½ acre	0.88	0.32
Lot more than 1 acre	0.02	0.14
Brick facing	0.39	0.49
Porch	0.49	0.50
Garage Bays	1.53	0.86

Table 3: Results of OLS Models			
VARIABLE	MODEL 1	MODEL 2	MODEL 3
Square feet (100)	0.0176*** (0.0005)	0.0176*** (0.0005)	0.0176*** (0.0006)
No air conditioning	-0.2756*** (0.0098)	-0.2756*** (0.0098)	-0.2756*** (0.0098)
Number of bathrooms	0.0983*** (0.0059)	0.0987*** (0.0059)	0.0987*** (0.0059)
Age	-0.0044*** (0.0002)	-0.0044*** (0.0002)	-0.0044*** (0.0002)
Number of rooms	0.0409*** (0.0025)	0.0406*** (0.0025)	0.0406*** (0.0025)
Brick facing	0.0872*** (0.0069)	0.0862*** (0.0069)	0.0862*** (0.0069)
Porch	0.1020*** (0.0063)	0.1022*** (0.0064)	0.1022*** (0.0063)
Garage Bays	0.0850*** (0.0046)	0.0848*** (0.0045)	0.0848*** (0.0045)
Lot less than ½ acre	-0.0939*** (0.0107)	-0.0918*** (0.0108)	-0.0916*** (0.0108)
Lot more than 1 acre	0.1955*** (0.0237)	0.1944*** (0.0237)	0.1944*** (0.0237)
Effective tax rate	-0.1451*** (0.0023)	-0.1450*** (0.0023)	-0.1450*** (0.0023)
Median neighborhood household income ($1,000)	0.0047*** (0.0002)	0.0047*** (0.0002)	0.0047*** (0.0002)
Center Township location	-0.3552*** (0.0126)	-0.3521*** (0.0127)	-0.3519*** (0.0127)
Percentage Non-white Population	-0.0024*** (0.0001)	-0.0025*** (0.0001)	-0.0025*** (0.0001)
Accessibility to employment (1,000)	0.0008*** (0.0002)	0.0007*** (0.0002)	0.0007*** (0.0002)
ISTEP	0.0008*** (0.0001)	0.0008*** (0.0001)	0.0008*** (0.0001)
Mile Density (1,000)	0.0204*** (0.0028)	0.0207*** (0.0028)	0.0207*** (0.0028)
Near Westside Area	-0.3166*** (0.0213)	-0.3157*** (0.0213)	-0.3157*** (0.0213)
Downtown/Lockerbie Area	0.8286*** (0.0279)	0.8320*** (0.0279)	0.8322*** (0.0279)
Meridian Kessler/Broad Ripple Area	0.5072*** (0.0164)	0.5072*** (0.0164)	0.5072*** (0.0164)
2_Acre NDVI	0.0012*** (0.0002)		0.0018*** (0.0003)
11_Acre NDVI		0.0017*** (0.0003)	
NDVI_Difference			0.0017*** (0.0006)
_cons	9.6663*** (0.1168)	9.6074*** (0.1184)	9.6038*** (0.1185)
R^2	0.8731	0.8732	0.8732

***:significant at 1%

TABLE 4 : Results from Spatial Lag Models

	MODEL 1		MODEL 2		MODEL 3	
	MLE	2-SLS (Robust)	MLE	2-SLS (Robust)	MLE	2-SLS (Robust)
Spatial Lag (ρ)	0.3679*** (0.0097)	0.3595*** (0.0126)	0.3672*** (0.0097)	0.3588*** (0.0126)	0.3672*** (0.0097)	0.3586*** (0.0126)
Square feet (100)	0.0156*** (0.0005)	0.0156*** (0.0006)	0.0156*** (0.0005)	0.0156*** (0.0006)	0.0156*** (0.0005)	0.0156*** (0.0006)
No air conditioning	-0.2623*** (0.0091)	-0.2627*** (0.0122)	-0.2622*** (0.0091)	0.2625*** (0.0121)	-0.2622*** (0.0091)	0.2626*** (0.0121)
Number of bathrooms	0.0801*** (0.0055)	0.0805*** (0.0066)	0.0803*** (0.0055)	0.0808*** (0.0066)	0.0803*** (0.0055)	0.0808*** (0.0066)
Age	-0.0038*** (0.0002)	-0.0038*** (0.0002)	-0.0038*** (0.0002)	0.0038*** (0.0002)	-0.0038*** (0.0002)	0.0038*** (0.0002)
Number of rooms	0.0400*** (0.0023)	0.0400*** (0.0024)	0.0399*** (0.0023)	0.0399*** (0.0024)	0.0399*** (0.0023)	0.0399*** (0.0024)
Brick facing	0.0680*** (0.0065)	0.0684*** (0.0055)	0.0676*** (0.0065)	0.0680*** (0.0055)	0.0676*** (0.0065)	0.0680*** (0.0055)
Porch	0.0970*** (0.0059)	0.0971*** (0.0059)	0.0971*** (0.0059)	0.0972*** (0.0059)	0.0971*** (0.0059)	0.0972*** (0.0059
Garage Bays	0.0794*** (0.0042)	0.0795*** (0.0051)	0.0793*** (0.0042)	0.0794*** (0.0051)	0.0793*** (0.0042)	0.0795*** (0.0051)
Lot less than ½ acre	-0.0617*** (0.0101)	-0.0625*** (0.0104)	-0.0609*** (0.0101)	-0.0616*** (0.0105)	-0.0609*** (0.0101)	-0.0616*** (0.0105)
Lot more than 1 acre	0.1811*** (0.0221)	0.1814*** (0.0237)	0.1806*** (0.0221)	0.1809*** (0.0238)	0.1806*** (0.0221)	0.109*** (0.0238)
Effective tax rate	-0.1360*** (0.0021)	-0.1362*** (0.0033)	-0.1360*** (0.0021)	0.1362*** (0.0033)	-0.1360*** (0.0021)	0.1362*** (0.0033)
Median neighborhood household income ($1,000)	0.0017*** (0.0002)	0.0018*** (0.0002)	0.0017*** (0.0002)	0.0017*** (0.0002)	0.0017*** (0.0002)	0.0017*** (0.0002)
Center Township location	-0.1708*** (0.0127)	-0.1750*** (0.0162)	-0.1699*** (0.0127)	0.1740*** (0.0162)	-0.1699*** (0.0127)	0.1715*** (0.0002)
Percentage Non-white Population	-0.0016*** (0.0001)	-0.0017*** (0.0002)	-0.0016*** (0.0001)	0.0017*** (0.0002)	-0.0016*** (0.0001)	0.0017*** (0.0002)
Accessibility to employment (1,000)	0.0017*** (0.0002)	0.0017*** (0.0002)	0.0017*** (0.0002)	0.0017*** (0.0002)	0.0017*** (0.0002)	0.0017*** (0.0002)
ISTEP	0.0002* (0.0001)	0.0002* (0.0001)	0.0002* (0.0001)	0.0002* (0.0001)	0.0002* (0.0001)	0.0002* (0.0001)
Mile Density	0.0163*** (0.0026)	0.0164*** (0.0029)	0.0164*** (0.0026)	0.0165*** (0.0029)	0.0164*** (0.0026)	0.0165*** (0.0029)
Near Westside Area	-0.0533*** (0.0211)	-0.0593** (0.0298)	-0.0491*** (0.0215)	-0.0595** (0.0298)	-0.0491*** (0.0215)	-0.0596** (0.0298)
Downtown/Lockerbie Area	0.6117*** (0.0266)	0.6167*** (0.0390)	0.6136*** (0.0266)	0.6186*** (0.0390)	0.6135*** (0.0266)	0.6187*** (0.0389
Meridian Kessler/Broad Ripple Area	0.3105*** (0.0161)	0.3147*** (0.0169)	0.3105*** (0.0161)	0.3150*** (0.0169)	0.3105*** (0.0161)	0.3151*** (0.0169)
2_Acre NDVI	0.0007*** (0.0002)	0.0007*** (0.0002)			0.0009†† (0.0003)	0.0009†† (0.0003)
11_Acre NDVI			0.0009*** (0.0003)	0.0009*** (0.0003)		
NDVI_Difference					0.0007†† (0.0005)	0.0007†† (0.0005)
_cons	6.1932***	6.2726***	6.1748***	6.2534***	6.1755***	6.1720***

	(0.1418)	(0.1589)	(0.1424)	(0.1589)	(0.1425)	(0.1612)
R^2	0.8853	0.8893	0.8854	0.8893	0.8854	0.8854
***: significant at 1% **:significant at 5% *:significant at 10 percent						
††: Jointly significant at 5%						

Table 5 Average Annual Marginal Willingness to Pay

	Discount Rate		
	4 percent	6 percent	8 percent
		1 percent increase	
Lower Bound	$46	$26	$15
Upper Bound	$92	$52	$30

Total Annualized Value for Permanent Increase

	Discount rate		
	4 percent	6 percent	8 percent
		1 percent increase	
Lower Bound	$ 9,598,317	$ 5,420,250	$ 3,093,731
Upper Bound	$ 19,196,634	$ 10,840,500	$ 6,187,463

Figure 1: Construct of NDVI Measures

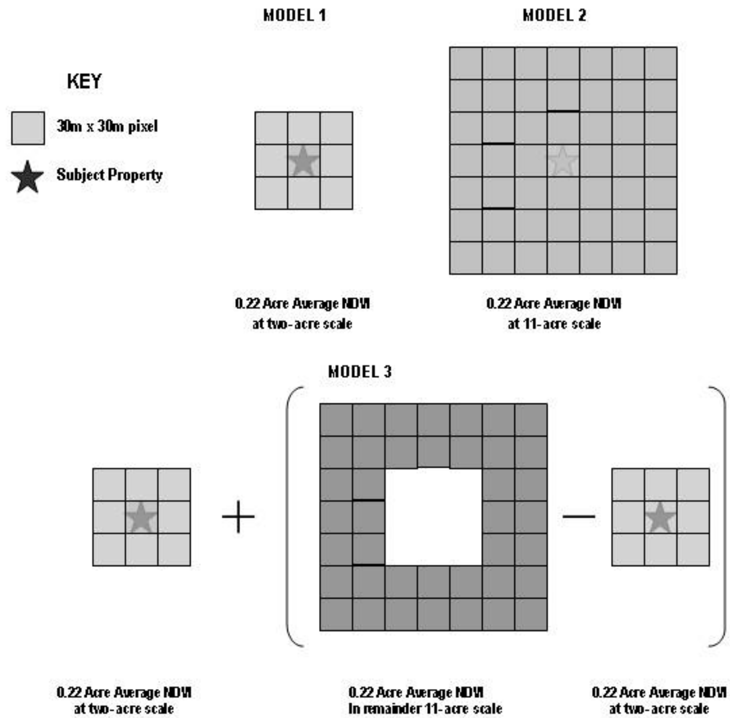
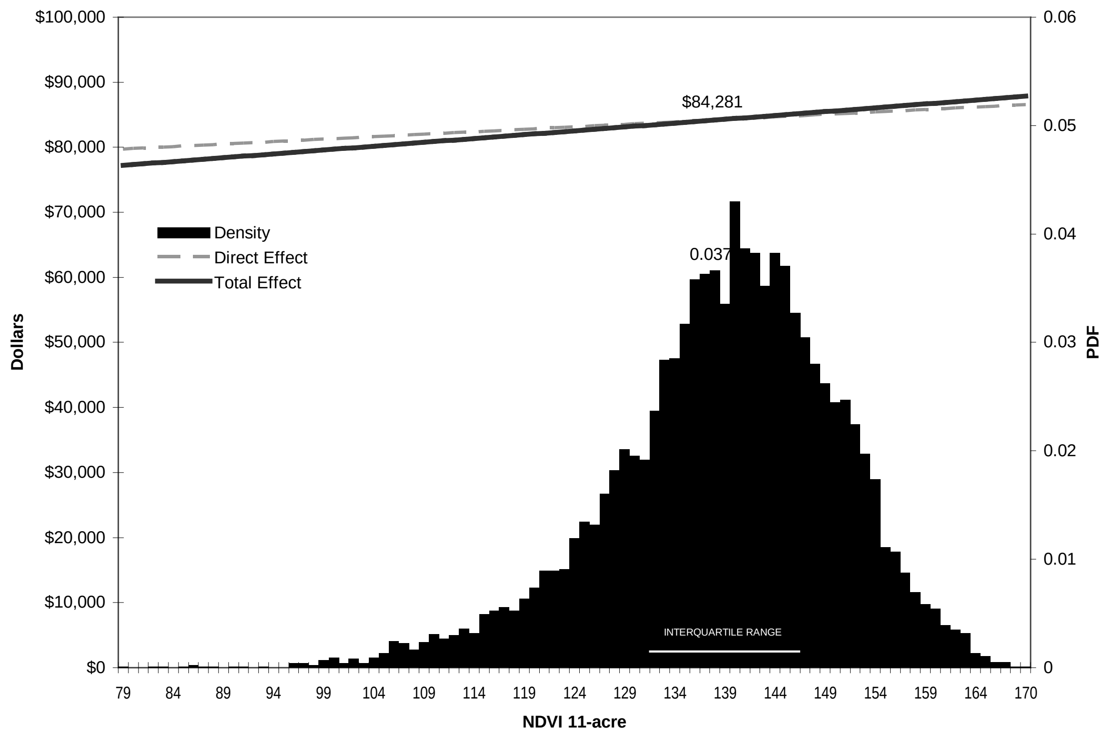


Figure 2: Direct and Total Price Effect Across Distribution Units Sold Along NDVI Spectrum (2004)



[1] The use of NDVI may be criticized as a coarse measure of urban forest. Data exist that allow for classification of land use types. However, those data are often collected at a regional scale and suffer from generalized classification when mixed land uses may exist in a given pixel. NDVI measures greenness and our study measures the effects of that measure on the premium paid.

[2] The use of logged sale price was also tested against sale price as the dependent variable. The test revealed that logged sale price was the best alternative. Examination of a histogram of price also supports the use of a semi-log model.

[3] Definitions range from contiguity matrices to various threshold distances, where contiguous properties or properties within a specified distance are identified as neighbors. A contiguity matrix identifies properties that are contiguous to each observation. A distance threshold matrix creates a binary variable for each observation within the specified threshold. The diagonal elements are set at zero, and row elements are standardized to sum to one. The result of that matrix is the average price of surrounding properties as an independent variable.

[4] The contiguity matrixes were constructed using thiessen polygons. Distance threshold matrices were based on point data. The log likelihood, Akiake Information Criterion (AIC), and the Schwartz Criterion were used to identify best model fit. That distance threshold is also consistent with how one may view the housing market.

[5] The original map layer used to construct the NDVI is based on 30m x 30m pixels (900 sq meters- or 0.25 acre pixels). The vegetation index for the 30-meter pixels in Marion County ranges from -0.7 to +0.7. Originally, the urban forest effects were constructed to consider NDVI at four different scales: (1) the 30m x 30m cell in which a property was located(Cell_NDVI); (2) the average of the 30m x 30m cell in which the property was located and the eight adjacent 30m x 30m pixels (2 acres surrounding property); the average of the 30m x 30m cell in which the property was located, the eight adjacent 30m x 30m pixels, and the next ring of 30m x 30m pixels (roughly 5.6 acres); and the average of the 30m x 30m cell in which the property was located and the three rings of 30m x 30m pixels (roughly 11 acres). The number of variables considered was reduced to two scales through exploratory analyses

[6] Center Township is the township that includes the oldest, inner city portion of Marion County. A large portion of that township is associated with negative externalities that are common to many inner city perceptions. One exception is the Downtown/Lockerbie area, which is completely encompassed by Center Township, but does not experience the same negative perceptions. The Meridian-Kessler/Broad Ripple area is partly in Center Township and also encompasses unique area of the Marion County housing market containing Broad Ripple (outside Center Township), a thriving commercial district surrounded mostly by relatively higher

priced, well maintained, and often privately rehabilitated older bungalows. The Near Westside area is an older area of the city outside of Center Township that experiences similar inner city negative externalities. The Center Township and Near Westside area binary variables are expected to correlate negatively with house price. Location within Meridian-Kessler/Broad Ripple and Downtown/Lockerbie areas are expected to correlate positively with house price. All neighborhood areas are approximated by Census block groups.

[7] A one percent increase is found by multiplying 0.01*138.90

[8] Annualized values are calculated by summing the product of the total effect of the 11acre NDVI by each house sale price in the sample and dividing by N, where N is the number of observations. That average value is then discounted over the life of the unit.

[9] 2000 Decenial Census. U.S. Census Bureau