Valuing Walkability and Vegetation in Portland, Oregon[1]

Niko Drake-McLaughlin and Noelwah R. Netusil
Reed College, Department of Economics
3203 SE Woodstock Blvd.
Portland, Oregon 97202-8199
(contact: netusil@reed.edu)

September 30, 2010

Draft: Please do not cite or quote without permission

Abstract
This study uses the hedonic price method to examine if vegetation on a property and in the surrounding neighborhood, and proximity to urban amenities, influence the sale price of single-family residential properties in a highly urbanized part of Portland, Oregon. We combine structural and location information for 21,869 single-family residential transactions with high-resolution land cover data and a walkability index developed by city planners. A one standard deviation increase in the walkability index, starting from its mean value, is estimated to increase a property's sale price from 0.84% to 7.29% with the largest effects occurring in areas with the highest levels of vegetation.

[1] Funding provided by an ULTRA-Ex, NSF award #0948983 and a Reed College Initiative Grants in Undergraduate Research. We greatly acknowledge assistance from Jonathan Kadish, Zach Levin, Gary Odenthal and Carmen Piekarski.

Valuing Walkability and Vegetation in Portland, Oregon

I. Introduction

An urban neighborhood's desirability depends on many factors including the amount, type and distribution of vegetation and whether residents have easy access to parks, shopping, schools and public transit. These factors are also related to broader environmental concerns. The amount and placement of vegetation can reduce stormwater runoff, improve water quality and enhance wildlife habitat (Metro 2008), and walkable, mixed-use neighborhoods have been found to reduce traffic congestion, improve air quality and reduce greenhouse gas emissions (Bureau of Planning and Sustainability 2009).

Portland, Oregon is ranked as the most sustainable city in the United States (Haight 2009), but it faces several environmental challenges resulting from a high percentage of impervious surface area, a sewer system in older neighborhoods that combines untreated sewage and stormwater runoff, and declines in steelhead trout and Chinook salmon populations that resulted in their listing as "threatened" under the Endangered Species Act (Bureau of Environmental Services 1999).

Approximately 35% of the city of Portland is classified as impervious, which includes "hard" surfaces such as roads, rooftops and driveways. This percentage is a byproduct of Oregon's 19 land use planning goals, specifically Goal 14, which requires urban growth boundaries be "established and maintained by cities, counties and regional governments to provide land for urban development needs and to identify and separate urban and urbanizable land from rural land" (Oregon Department of Land Conservation and Development 2006). While the Portland metropolitan area's urban growth boundary has contained sprawl, the density of development has resulted in an amount of impervious surface area that exceeds the level past which water quality is found to degrade rapidly (Booth, Hartley, and Jackson 2002).

Oregon's water quality index scores for the Lower Willamette Basin, which includes the Portland metropolitan area, range from good to very poor. Water quality at a monitoring site located in downtown Portland is "impacted by high concentrations of fecal coliform, total phosphates, nitrate and ammonia nitrogen, and biochemical oxygen demand with additional influence from high total solids" (Oregon Department of Environmental Quality). The poorest ratings occur during winter when "Portland's combined sewer/stormwater system is under the most pressure and overflows are most likely to occur" (Oregon Department of Environmental Quality).

To reduce the volume of untreated discharges coming from Portland's combined sewer system, the city of Portland implemented a series of programs to reduce the amount of stormwater entering the system and to increase the physical capacity of its treatment facilities. This "physical capital" approach is complemented by a "natural capital" approach, the Grey to Green Program, that aims to plant 33,000 yard trees and 50,000 street trees, add 43 acres of ecoroofs, construct 920 green street facilities, and purchase 419 acres of natural areas over a 5-year period (Bureau of Environmental Services 2010).

Portland is also exploring, as part of an update to its long-range development plan, the "20-minute neighborhood" concept which would lead to the redevelopment of neighborhoods to improve access to urban amenities such as shopping, schools, public transit and parks. This is expected to decrease residents' transportation expenditures, reduce pollution, increase safety by having more people on the street, and encourage healthier lifestyles by promoting walking and biking. Economic benefits include a likely increase in housing values, reduction in infrastructure costs, ability to attract workers and new businesses, and an increase in tourism (Bureau of Planning and Sustainability 2009).

The research on walkability and the sale price of single-family residential properties finds mixed results about factors, such as proximity to bus stops and shopping, which contribute to walkability. The majority of studies find that vegetation increases the sale price of single-family residential properties in urban areas, but no research has included both walkability and vegetation or examined if a relationship exists between these variables. Because they are likely to be negatively correlated, studies that look at just one variable may produce biased estimated coefficients thereby leading to inaccurate policy recommendations.

Our paper is structured as follows. The next section reviews the literature on property values, walkability and vegetation. Section III provides background information about the study area and data used in our analysis. Models are presented in Section IV with results and key findings in Section V. The final section concludes and offers policy recommendations.

II. Literature Review

There is a rich literature investigating the effects of vegetation on the sale price of single-family residential properties in urban areas. Donovan and Butry (2010) estimate the effect of street trees on the sale price of single-family residential properties on the east side of Portland, Oregon. In addition to finding a statistically significant increase in sale price of $8,870 (3% of the median sales price) from the combined effect of street trees in front of a property, and canopy from street trees within 100 feet of a property, the authors find that street trees reduce a property's average time on market by 1.7 days.

Numerous studies examine the effect of urban forests on the sale price of residential properties. While studies find a positive effect from proximity to urban forests (Mansfield et al. 2005; Tyrvainen and Miettinen 2000), the evidence on forest views is mixed with studies finding a positive effect (Tyrvainen and Miettinen 2000), a negative effect (Paterson and Boyle 2002), or effects that vary by tree type (Garrod and Willis 1992).

A modeling approach used by several authors includes the amount of the area surrounding a property classified as forested (Mansfield et al. 2005; Netusil, Chattopadhyay, and Kovacs 2010; Paterson and Boyle 2002; Payton 2008) or that have trees, and other kinds of vegetation, as land use categories (Acharya and Bennett 2001; Geoghegan, Wainger, and Bockstael 1997). Important findings from these studies include evidence of diminishing returns from tree canopy (Netusil, Chattopadhyay, and Kovacs 2010) and the superiority of models that incorporate spatial patterns compared to a more traditional approach that includes straight-line distance to certain land use/land cover types (Acharya and Bennett 2001).

While research in the Portland metropolitan area has examined if proximity to specific urban amenities such as open spaces (Lutzenhiser and Netusil 2001), wetlands (Mahan, Polasky, and Adams 2000), and public transit (Chen, Rufolo, and Dueker 1998) affect the sale price of single family residential properties, the literature on walkability's effect is limited to one study that evaluates the importance of neighborhood design on the west side of the Portland metropolitan area (Song and Knaap 2003). The authors find mixed results for variables that capture walkability—properties with easier access to commercial uses, measured as the percentage of land within ¼ mile of a property classified as commercial, are found to sell for a premium while properties close to bus stops sell for a discount.

The modeling approach that is closest to the one used in our study is Pivo and Fisher's (2010) analysis of how walkability, measured using a value generated by walkscore.com, affects the market value of office, retail, apartment and industrial properties. A 10-point increase in walkability, which is measured on a 100-point scale, is estimated to increase property values by 1 percent for apartments and 9 percent for office and retail properties. No statistically significant effect was found for industrial properties.

Pivo and Fisher (2010) note several limitations from using walkscore.com including its assignment of equal weights to urban amenities such as schools, parks, retail establishments, etc. that are located within buffers of up to 1 mile from a property. Barriers to walking, such as highways, rivers and steep slopes, and access to mass transit, are not taken into account in walkscore's algorithm, which uses a straight-line distance to amenities. The walkability index used in our analysis, which is described in detail below, overcomes these limitations.

III. Data and Study Area

Our data set includes 21,869 single-family residential transactions that occurred between January 1st, 2005 and December 31st, 2007 in a highly urbanized part of the city of Portland, Oregon. The data, which are from the Multnomah County Assessor's office, were evaluated to make sure that transactions occurred at arms length. Summary statistics, which are broken down by the five areas of Portland (North, Northeast, Northwest, Southwest and Southeast), are presented in Table 1. Sale price is in 2007 dollars after deflating using the CPI-U.

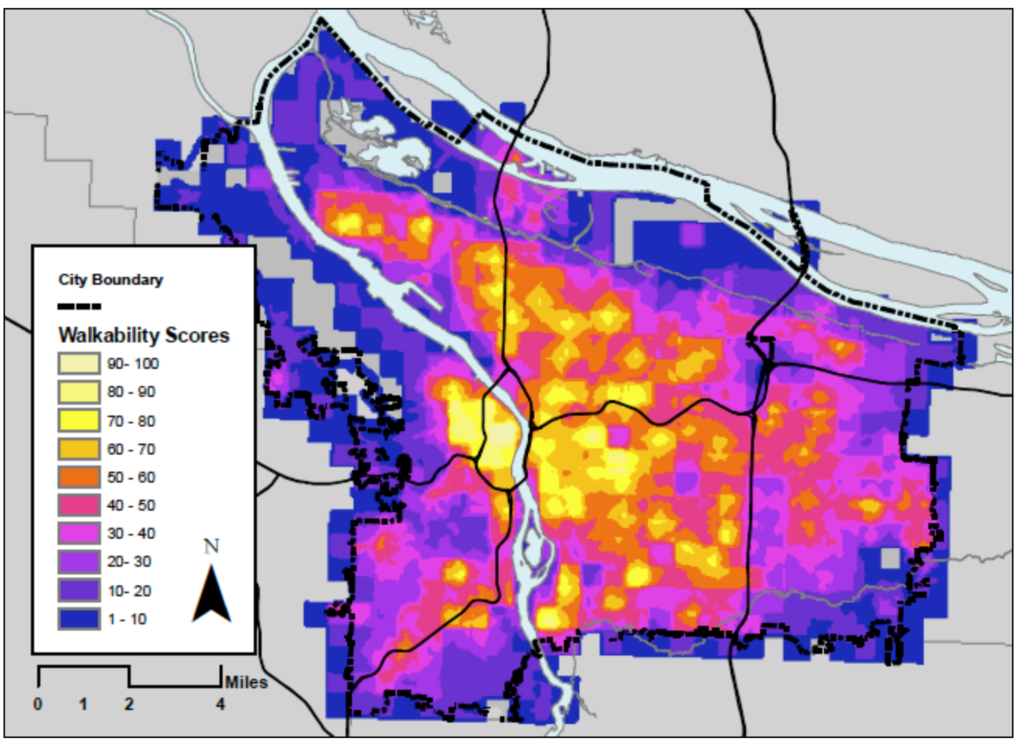
Table 1: Summary Statistics for House Sales by Area

Variable	Number of Observations	Mean	Standard Deviation	Minimum	Maximum
realsaleprice (study area)	21,869	307,247	167,339	58,921	2,904,564
realsaleprice (N Portland)	3,528	250,409	79,058	64,795	993,354
realsaleprice (NE Portland)	7,043	317,340	147,653	63,043	1,572,029
realsaleprice (NW Portland)	256	693,478	339,832	107,527	2,750,810
realsaleprice (SW Portland)	2,198	459,942	278,963	103,560	2,904,564
realsaleprice (SE Portland)	8,844	272,753	118,555	58,921	1,903,024

Land cover information was derived from a 2007 land cover layer that classifies each 3x3 foot square in the study area as high structure vegetation (trees), low structure vegetation (grass, shrubs and small trees), impervious surface or open water (rivers, streams and lakes) (Metro Data Resource Center 2007). The proportion of each land cover type was computed for each property, within 200 feet of each property, between 200 feet and ¼ mile, and between ¼ mile and ½ mile of each property. Neighborhood data, such as distance to major arterial roads, distance to highways, slope and elevation were derived using data layers maintained by the regional government's data resources center (Metro Data Resources Center 2009). Median income and proportion white at the census tract level were derived from the 2000 U.S. Census (U.S. Census Bureau 2009).

A walkability index, which is illustrated in Figure 1, was created by staff at the Portland Bureau of Planning and Sustainability as part of the “20-minute neighborhood” concept. The index takes into account several variables, such as the actual walking distance to full service grocery stores, elementary schools and parks, and if streets are steeply sloped. Also, the city was divided into ½ mile by ½ mile grid cells and the number of commercial businesses, the percentage of sidewalk coverage, the number of intersections and the level of public transit in each grid cell was computed, weighted, and then incorporated into the index. Scores range from 1-100 for the city of Portland with the scores for our observations ranging from 1-83.

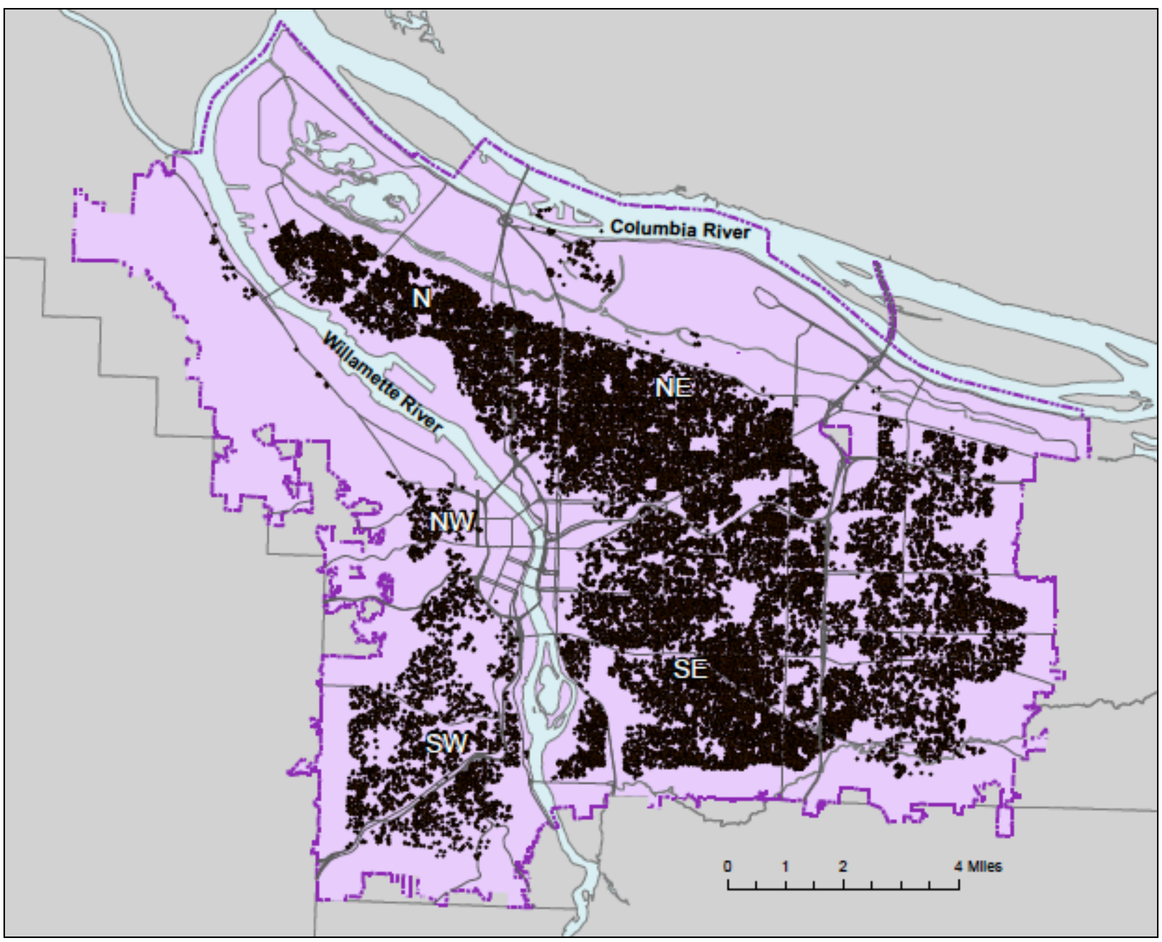
Figure 1: Walkability Index for City of Portland, Oregon



Lynch and Rasmussen (2001) find that high crime areas have a negative effect on the sale price of properties, so we created a crime index using ArcGIS software and data from the Bureau of Planning and Sustainability. Different weights were assigned to homicides, larceny, assault, robbery, burglary, drug violations and prostitution based on their seriousness, with homicide having the heaviest weight and prostitution and drug violations the least.[2] The crime index distribution is very skewed, so a natural logarithm was used in our regressions to minimize the effect of outliers.

Because data are not consistently available for urban amenities outside the city of Portland, observations within ½ mile of the city limits may have inaccurate walkability index values, so these observations were dropped from our analysis. The 21,869 property sales used in our analysis are shown in Figure 2.

Figure 2: Property Sales in Portland, Oregon



---

2 Crime indexes with different weighting schemes were also examined. Regression results were very similar to those reported in the final specifications.

The regression specification includes detailed structural, location and environmental characteristics. The names and descriptions for variables used in the regression are provided in Table 2.

Table 2: Variable Names and Descriptions

Variable Name	Variable Description
walkability	Walkability index score
prop_high	Proportion high structure vegetation on property
prop_low	Proportion low structure vegetation on property
prop_imp	Proportion impervious surface on property
prop_water	Proportion water on property
prop_hv_200	Proportion high structure vegetation within 200 feet
prop_lv_200	Proportion low structure vegetation within 200 feet
prop_imp_200	Proportion impervious surface within 200 feet
prop_wa_200	Proportion water within 200 feet
prop_hv_1320	Proportion high structure vegetation between 200 feet and 1/4 mile
prop_lv_1320	Proportion low structure vegetation between 200 feet and 1/4 mile
prop_imp_1320	Proportion impervious surface between 200 feet and 1/4 mile
prop_wa_1320	Proportion water between 200 feet and 1/4 mile
prop_hv_2640	Proportion high structure vegetation between 1/4 mile and 1/2 mile
prop_lv_2640	Proportion low structure vegetation between 1/4 mile and 1/2 mile
prop_imp_2640	Proportion impervious surface between 1/4 mile and 1/2 mile
prop_wa_2640	Proportion water between 1/4 mile and 1/2 mile
lotsqft	Lot square footage
bldgsqft	House square footage
fullbaths	Number of full bathrooms
halfbaths	Number of half bathrooms
age	Year house was sold minus year house was built
numfire	Number of fireplaces
N, NE, NW, SW, SE	Dummy variables for areas of the city
dist_N, dist_NE, dist_NW, dist_SW, dist_SE (feet)	Area variables interacted with distance to CBD
elevation (feet)	Elevation of property in feet
medianincome ($)	Median income of census tract in dollars

crime	Crime index score
proportionwhite	Proportion of census tract that is white
prop_slope10%	Proportion of property with a slope greater than 10%
Month 1-36	Dummy variables indicating sale month of transaction
maj_art330, maj_art660, maj_art1320, maj_art2640	Dummy variables indicating whether a property is within 330, 660, 1320, or 2640 feet of a major arterial road
fwy 330, fwy660, fwy1320, fwy2640	Dummy variables indicating whether a property is within 330, 660, 1320 or 2640 feet of a freeway

Summary statistics for key variables are provided in Table 3. Lot sizes are small averaging 6,367 square feet; on average, 45% of our lots are covered by impervious surface area followed by approximately 29% low structure vegetation (grass, shrubs and small trees), and 26% high structure vegetation (trees). Eighteen properties have water on the property itself, so the average lot coverage for this variable is very small. The land cover percentages remain fairly constant in the buffers (200 feet, 200 feet to ¼ mile and ¼ mile to ½ mile) surrounding our properties. Impervious surface area in the buffers ranges from around 47% to 48%, low structure vegetation from 27% to 28%, while high structure vegetation is approximately 25% in all three buffers.

Table 3: Summary Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
walkability	47.69	13.22	1	83
prop_high	.2601	.2179	0	1
prop_low	.2942	.1935	0	1
prop_imp	.4457	.1921	0	1
prop_water	.0000302	.0015	0	.1418
prop_hv_200	.2505	.1327	0	.9921
prop_lv_200	.2831	.1003	0	.7801
prop_imp_200	.4661	.1220	0	.9565
prop_wa_200	.0003303	.007874	0	.3565
prop_hv_1320	.2467	.1137	.02431	.9213
prop_lv_1320	.2742	.07775	.01124	.6749
prop_imp_1320	.4768	.1091	.04586	.9384
prop_wa_1320	.0022231	.01790	0	.5023
prop_hv_2640	.2453	.1070	.05623	.8355
prop_lv_2640	.2673	.0703	.0054	.6315
prop_imp_2640	.4782	.1058	.0661	.8658
prop_wa_2640	.0091452	.0373	0	.5491
lotsqft	6,367.04	4,420.60	1,192	173,991
bldgsqft	1,9188.37	817.62	396	12,061
fullbaths	1.54	.6538	0	6
halfbaths	.2703	.4736	0	4
age	61.53	29.75	0	128
numfire	.8136	.6717	0	6
dist	24,101.20	9,137.66	3,415.31	49,965.3
elevation	226.62	119.01	10	1,040
medianincome	43,630	12,304	14,091	108,931
crime	2.50	3.14	1	36
lncrime	.5193	.7569	0	3.58
proportionwhite	.7642	.1334	.2943	.9571

V. Results

The theoretical basis for the hedonic price method is firmly established in the literature (Freeman 2003). The appropriate functional form for estimation is less clear with most researchers using the semi-log (Taylor 2003).

Results of five semi-log models are presented in Table 4. Models 1 and 2 include just the walkability index and vegetation variables, respectively. Model 3 includes both variables, Model 4 adds interaction terms, and Model 5 is a spatial error model using a 4 nearest-neighbor weight matrix. Quadratic terms are included for the vegetation variables (high structure and low structure) and for the walkability index because we believe there is some point past which increases in these variables will decrease a property's sale price—a modeling approach informed by research in the study area (Netusil, Chattopadhyay, and Kovacs 2010). We predict that water on a property will always decrease its sales price due to risks of flooding and other hazards, while water in the buffers surrounding a property will always increase sale price. Impervious surface is the excluded variable in all models.

A Breusch-Pagan/Cook-Weisberg test indicates heteroskedasticity in all models, so robust regressions were run for OLS models. All of the control variables have the expected sign and magnitude, and most are statistically significant. Full regression results are available from the authors.

Table 4: Regression Results

Variables	Model 1 (OLS)	Model 2 (OLS)	Model 3 (OLS)	Model 4 (OLS)	Model 5 (SEM 4NN)
walkability	0.1240*		0.5900***	-0.5248***	-0.5484***
	(0.0683)		(0.7190)	(0.1437)	(0.1306)
walkability2	0.0101		-0.3291***	-0.0129	0.0001
	(0.0719)		(0.0734)	(0.0897)	----
prop_high		0.0454**	0.0418**	-0.1378***	-0.1475***
		(0.2000)	(0.0199)	(0.0404)	(0.0399)
prop_high2		-0.0987***	-0.0973***	-0.0752***	-0.0612**
		(0.0258)	(0.0256)	(0.0260)	(0.0255)
walkability* prop_high				0.3414***	0.3531***
				(0.0664)	(0.0654)
prop_low		-0.0281	-0.0324	-0.1146***	0.2083***
		(0.0249)	(0.0248)	(0.0434)	(0.0694)
prop_low2		-0.0521	-0.0472	-0.0610*	-0.0414
		(0.0333)	(0.0331)	(0.0331)	(0.0318)
walkability* prop_low				0.1790***	0.2083***
				(0.0705)	(0.0694)
prop_water		-5.4901***	-5.1829***	-6.0805**	-4.7925*
		(0.8977)	(0.8922)	(2.9617)	(2.8191)
walkability* prop_water				7.6690	3.6869
				(13.1438)	(12.2897)
prop_hv_200		0.1500***	0.1711***	-0.2789***	-0.2393***
		(0.0422)	(0.0419)	(0.0823)	(0.0886)
prop_hv2_200		-0.0709	-0.0939	0.0492	0.0296
		(0.0624)	(0.0620)	(0.0668)	(0.0296)
walkability* prop_hv_200				0.8119***	0.7475***
				(0.1286)	(0.1410)
prop_lv_200		0.4475***	0.4222***	0.1661	0.2367*
		(0.0775)	(0.0771)	(0.1123)	(0.1246)
prop_lv2_200		-0.4672***	-0.4116***	-0.3802***	-0.4169***
		(0.1212)	(0.1205)	(0.1222)	(0.1345)
walkability* prop_lv_200				0.5053***	0.4091***
				(0.1495)	(0.1636)
prop_wa_200		0.9779***	1.1536***	-0.8784**	-0.7898*
		(0.2055)	(0.2051)	(0.4135)	(0.4388)
walkability*				9.0022***	7.3449***

prop_wa_200					
				(1.7171)	(1.8362)
prop_hv_1320		0.2288***	0.3056***	0.2455	0.2982
		(0.0747)	(0.0746)	(0.1627)	(0.1988)
prop_hv2_1320		0.1642	0.2182**	0.3254**	0.2223
		(0.1086)	(0.1081)	(0.1319)	(0.1588)
walkability* prop_hv_1320				0.0532	0.0899
				(0.2476)	(0.2997)
prop_lv_1320		0.1475	0.1319	0.4852**	0.4066
		(0.1472)	(0.1465)	(0.2212)	(0.2711)
prop_lv2_1320		-0.0454	0.1784	0.1907	0.2554
		(0.2340)	(0.2331)	(0.2514)	(0.3193)
walkability* prop_lv_1320				-0.8074***	-0.7138**
				(0.2684)	(0.3245)
prop_wa_1320		0.1366	0.2590**	0.5417*	0.5147
		(0.1071)	(0.1067)	(0.2920)	(0.3431)
walkability* prop_wa_1320				-1.2204*	-1.0501
				(0.6639)	(0.8078)
prop_hv_2640		0.5916***	0.5375***	0.6808***	0.6525***
		(0.0803)	(0.0799)	(0.1528)	(0.1919)
prop_hv2_2640		-0.7457***	-0.5432***	-0.7792***	-0.7371***
		(0.1170)	(0.1174)	(0.1341)	(0.1675)
walkability* prop_hv_2640				-0.1913***	-0.1621
				(0.2230)	(0.2702)
prop_lv_2640		0.7028***	0.5060***	-0.7726***	-0.7664***
		(0.1756)	(0.1751)	(0.2279)	(0.2839)
prop_lv2_2640		-0.8868***	-0.5269*	-0.0465	-0.0329***
		(0.3020)	(0.3009)	(0.3065)	(0.3290)
walkability* prop_lv_2640				2.1929***	2.1863***
				(0.2600)	(0.3215)
prop_wa_2640		0.4010***	0.4408***	0.6534***	0.7413***
		(0.0517)	(0.0514)	(0.1684)	(0.2059)
walkability* prop_wa_2640				-0.5233*	-0.6946*
				(0.3253)	(0.4086)
					rho = 0.263
Observations	21,869	21,869	21,869	21,869	21,869
R-squared	0.7399	0.7763	0.7792	0.7818	0.7944

*** p0.01, ** p<0.05, * p<0.1

Models 1 and 2 are included to compare the effect of modeling these variables individually with models that include both variables (Model 3) and interaction terms (Model 4). The estimated coefficient for walkability is statistically significant at the 10% level in Model 1, but the quadratic term is not significant. The magnitude, significance, and sign of the quadratic walkability coefficient change in Model 3 when the land cover variables are included providing strong evidence of omitted variable bias in Model 1. Interestingly, a comparison of estimated coefficients for the land cover variables in Models 2 and 3 does not provide strong evidence of omitted variable bias.

The estimated coefficients on both walkability terms in Model 3 are statistically significant, as are many of the land cover variables. Walkability is estimated to have a positive effect up to 90, which is outside the range of our data (the maximum value is 83), but below the maximum possible value of 100. A one standard deviation increase (13.22 points) in the walkability index for a property, starting from the mean score of 47.69, is predicted to increase a property's sale price by $20,289 (6.60%) using the average sale price of properties in our data set.

The linear and squared terms for on-property high structure vegetation are statistically significant; sale price is maximized when on-property high structure vegetation coverage is 23.04%, which is 3 percentage points lower than our study area average. Increasing high structure vegetation in the 200-foot and 200 foot to ¼ mile buffer surrounding a property is predicted to always increase a property's sale price, while the furthest buffer from a property, ¼ mile to ½ mile, shows diminishing returns to high structure vegetation.

The estimated coefficients for low structure vegetation are mixed with both the linear and quadratic term being significant for the 200 foot and ¼ mile to ½ mile buffers, but neither term is significant on a property or in the ¼ mile to ½ mile buffer. Water on a property is significantly negative, as expected, and water in the surrounding buffers is significantly positive, which is also expected.

The fourth model adds interaction terms to Model 3. Nine of the twelve interaction variables are statistically significant providing evidence of a relationship between walkability and land cover. Model 5 is a spatial error model that uses a 4 nearest-neighbor weight matrix.

Following the steps outlined in Anselin (2005), we ran spatial error models and spatial autoregressive models using a 4, 8 and 16-nearest neighbor weight matrix. Lagrange multiplier (LM) error values increased as the number of nearest neighbors increased, while the LM lag values declined. These test statistics, and the stronger theoretical justification for spatial error in hedonic models (Anselin and Lozano-Gracia 2009), leads us to prefer the spatial error model over the spatial autoregressive model. Estimated coefficients are similar across spatial error models, so we focus on the 4 nearest-neighbor model in our discussion of results.

Table 5 includes predictions of a one standard deviation increase in the walkability index, from its mean value, evaluated at the 25th, 50th and 75th percentile of high and low structure vegetation for all buffers. Results using the estimated coefficients from Model 4 range from 1.13% of the mean sale price for properties when high and low structure vegetation are at the 25th percentile to 7.29% when they are at the 75th

percentile. Results under the spatial error model (Model 5) are smaller with effects ranging from 0.84% at the 25th percentile to 7.02% for the 75th percentile.

Table 5: Predicted Effect of a One Standard Deviation Increase in Walk Score Evaluated at Mean Sale Price and Mean Walkability Index

Predicted increase in sale price of a one standard deviation increase in walkability index	High and Low Structure Vegetation at 25th Percentile For All Buffers	High and Low Structure Vegetation at 50th Percentile For All Buffers	High and Low Structure Vegetation at 75th Percentile For All Buffers
Model 4: Ordinary Least Squares	\$3,477 (1.13%)	\$11,987 (3.90%)	\$22,387 (7.29%)
Model 5: Spatial Error Model 4 Nearest Neighbors	\$2,590 (0.84%)	\$11,147 (3.63%)	\$21,569 (7.02%)

Table 6 holds walkability constant at its 25th, 50th and 75th percentile values and shows the predicted effect from increasing on-property high structure vegetation from the dataset average of 26.01% to the target tree canopy amount (35%-40%) specified for residential property in the city of Portland's Urban Forest Action Plan (Urban Forest Action Plan 2007).

Table 6: Predicted Effect of Increasing On-Property High Structure Vegetation OLS and SEM (4 nearest-neighbor) models

	Walkability index at 25th percentile (score of 39)	Walkability index at 50th percentile (score of 49)	Walkability index at 75th percentile (score of 57)
Predicted effect of achieving 35% high structure vegetation on property	OLS: -\$1,092 SEM: -\$978	OLS: -\$145 SEM: -\$1	OLS: \$598 SEM: \$768
Predicted effect of achieving 40% high structure vegetation on property	OLS: -\$1,856 SEM: -\$1,650	OLS: -\$379 SEM: -\$129	OLS: \$778 SEM: \$1,070

The amount of high structure vegetation that maximizes a property's sale price varies with its walkability score. Using estimated coefficients from Model 4, the amount of high structure vegetation on a property that is estimated to maximize its sale price equals 0.03% when the walkability index is at the 25th percentile, 26.82% at the 50th percentile, and 45.69% for the 75th percentile. These figures are 0.007%, 45.69% and 54.31% in the SEM model. This variation in "optimal" amounts of tree canopy explains why increasing tree canopy when the walkability index is at the 25th or 50th percentile decreases a property's sale price. Predicted effects for the 75th percentile are positive, but small compared to the cost of planting and caring for a tree (McPherson et al. 2002).

IV. Policy Implications and Conclusions

This paper has highlighted the importance of two key factors in determining the sale price of residential properties in an urban area: access to urban amenities, captured by a walkability index, and land cover on a property and in the surrounding neighborhood. Models that use one variable or the other likely suffer from omitted variable bias. Models that include both variables, and interaction terms, show that effects on sale price depend on the other variable's level with increases in high structure vegetation having a negative predicted effect when walkability is below approximately the 50th percentile. Increases in walkability, holding high and low structure vegetation constant, is predicted to increase a property's sale price with the largest effect occurring for properties with a high amount of low and high structure vegetation (75th percentile) on the property and in the surrounding buffers.

It is possible that these effects arise from scarcity of walkability and high levels of high structure vegetation in the same area. If an area is very walkable, it may be further from parks and closer to retail areas that have more impervious surfaces. Areas with a high proportion of trees may be less likely to have lots of businesses nearby. Nevertheless, the data does suggest that increasing both of these factors should have statistically and economically significant effects on a property's sale price and that the greatest effect comes from increasing the two in a coordinated effort.

Our results indicate that increasing walkability and vegetation should be pursued, and that both are beneficial for single-family residential property owners, but neither goal should be achieved at the expense of the other. How cities accomplish this goal, and what combination of walkability and vegetation are best for environmental and social goals, remain questions for future research.

References

Acharya, Gayatri, and Lynne Lewis Bennett. 2001. Valuing open space and land-use patterns in urban watersheds. *Journal of Real Estate Finance and Economics* 22 (2-3):221-237.

Anselin, L. 2005. Exploring Spatial Data with GeoDaTM : A Workbook edited by U.-C. University of Illinois. Urbana.

Anselin, Luc, and Nancy Lozano-Gracia. 2009. Spatial Hedonic Models. In *Palgrave Handbook of Econometrics*, edited by T. C. Mills and K. Patterson. Hampshire, England: Palgrave Macmillan.

Booth, Derek B., David Hartley, and Rhett Jackson. 2002. Forest Cover, Impervious Surface Area, and the Mitigation of Stormwater Impacts. *Journal of the American Water Resources Association* 38:835-845.

Bureau, U.S. Census. 2009. American FactFinder.

Center, Metro Data Resource. *Regional Land Information System* 2009.

Chen, Hong, Anthony Rufolo, and Kenneth J. Dueker. 1998. Measuring the impact of light rail systems on single-family home values - A hedonic approach with geographic information system application. *Land Use and Transportation Planning and Programming Applications* (1617):38-43.

Development, Oregon Department of Land Conservation and. 2006. Oregon's Statewide Planning Goals & Guidelines Goal 14: Urbanization. edited by O. D. o. L. C. a. Development.

Donovan, Geoffrey H., and David T. Butry. 2010. Trees in the city: Valuing street trees in Portland, Oregon. *Landscape and Urban Planning* 94:77-83.

Freeman, A. Myrick. 2003. *The Measurement of Environmental Resource Values*. 2nd ed. Washington, D.C.: Resources for the Future.

Garrod, Guy D., and Ken G. Willis. 1992. The Environmental Economic-Impact of Woodland: A 2-Stage Hedonic Price Model of the Amenity Value of Forestry in Britain. *Applied Economics* 24 (7):715-728.

Geoghegan, J, LA Wainger, and NE Bockstael. 1997. Spatial landscape indices in a hedonic framework: an ecological economics analysis using GIS. *Ecological Economics* 23 (3):251-264.

Haight, Abby. 2009. Portland Gets Its Reward: Most Sustainable City. *The Oregonian*.

Lutzenhiser, Margot, and Noelwah R. Netusil. 2001. The Effect of Open Spaces on a Home's Sale Price. *Contemporary Economic Policy* 19 (3):291-298.

Lynch, Allen K., and David W. Rasmussen. 2001. Measuring the Impact of Crime on House Prices. *Applied Economics* 33 (15):1981-1989.

Mahan, Brent L., Stephen Polasky, and Richard M. Adams. 2000. Valuing Urban Wetlands: A Property Price Approach. *Land Economics* 76 (1):100-113.

Mansfield, Carol, Subhrendu K. Pattanayak, William McDow, Robert McDonald, and Patrick Halpin. 2005. Shades of Green: Measuring the value of urban forests in the housing market. *Journal of Forest Economics* 11 (3):177-199.

McPherson, E. Gregory, Scott E. Maco, James R. Simpson, Paula J. Peper, Qingfu Xiao, Ann Marie VanDerZanden, and Neil Bell. 2002. Western Washington and Oregon Community Tree Guide: Benefits, Costs, and Strategic Planting.

Center for Urban Forest Research, USDA Forest Service, Pacific Southwest Research Station.
Metro. 2008. State of the Watersheds Monitoring Report, Initial report: Baseline watershed conditions as of Dec. 2006.
Metro Data Resource Center. 2009. *2007 High Resolution Landcover* 2007 [cited June 8 2009]. Available from http://rlismetadata.oregonmetro.gov/display.cfm?Meta_layer_id=2303&Db_type=rlislite.
Netusil, Noelwah R., Sudip Chattopadhyay, and Kent Kovacs. 2010. Estimating the Demand for Tree Canopy: a Second-Stage Hedonic Price Analysis in Portland, Oregon. *Land Economics*.
Paterson, Robert W., and Kevin J. Boyle. 2002. Out of Sight, Out of Mind? Using GIS to Incorporate Visibility in Hedonic Property Value Models. *Land Economics* 78 (3):417-425.
Payton, Seth, Greg Lindsey, Jeff Wilson, John R. Ottensmann and Joyce Man. 2008. Valuing the Benefits of the Urban Forest: A Spatial Hedonic Approach. *Journal of Environmental Planning and Management* 51 (6):717-736.
Pivo, Gary and Jeffrey D. Fisher. 2010. The Walkability Premium in Commercial Real Estate Investments. In *Responsible Property Investesting Center, University of Arizona; Benecki Center for Real Estate Studies, Indiana University*.
Quality, Oregon Department of Environmental. Oregon Water Quality Index Report for Lower Willamette, Sandy, and Lower Columbia Basins Water Years 1986-2995.
Services, Bureau of Environmental. 1999. Steelhead and Chinook Salmon Listing Portland's Response to the Endangered Species Act.
———. 2010. Portland's Green Infrastructure: Quantifying the Health, Energy, and Community Livability Benefits. edited by B. o. E. Services. Portland.
Song, Y., and G. J. Knaap. 2003. New urbanism and housing values: a disaggregate assessment. *Journal of Urban Economics* 54 (2):218-238.
Sustainability, City of Portland Bureau of Planning and. 2009. Status Report: Twenty-Minute Neighborhoods.
———. 2009. Status Report: Twenty-minute Neighborhoods.
Taylor, Laura O. 2003. The Hedonic Method. In *A Primer on Nonmarket Valuation*, edited by P. A. Champ, Kevin J. Boyle and Thomas C. Brown. Norwell, MA: Kluwer Academic Publishers.
Tyrvainen, Liisa, and Antti Miettinen. 2000. Property prices and urban forest amenities. *Journal of Environmental Economics and Management* 39 (2):205-223.
Urban Forest Action Plan. 2007. Portland: Portland Parks & Recreation.