Evaluating Private Demand for and Distribution of Urban Canopy Cover

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Abstract

Using a hedonic framework, I model consumers' behavior in the housing market to estimate private demand for urban tree canopy in Portland, Oregon. I then estimate willingness-to-pay for tree canopy as a function of demographic characteristics of an area's residents. To accomplish this, a Geographic Information System (GIS)-based analysis is used to determine proportions of ACS-defined block groups covered by tree canopy. This data is then regressed against house price, along with structural and neighborhood characteristics. The resulting willingness-to-pay estimation is then regressed against demographic characteristics. I find a that an increase in tree canopy is associated with a significant and substantive increase in house price, and that resident age, household size, and presence of a bachelor's degree are important determinants of willingness-to-pay for tree canopy.

Keywords: Urban Tree Canopy, Valuation of Environmental Effects, Land Use Patterns, Housing Supply and Markets
JEL Codes: Q51, R14, R31

Contents

1 Introduction

To a large extent, residents' differential access to urban amenities determines the form of a city. Amenity access, or the lack thereof, plays a major role in determining prices in housing markets throughout cities. By influencing housing prices, amenity access creates zones of differential economic welfare as residents choose to locate as close to important amenities as their means will allow. It is often unclear, however, to what degree the presence or absence of certain amenities generates demand for housing. In this paper, I assess the amenity value of urban tree canopy and its relationship to the housing market of Portland, Oregon.

This analysis occurs in two stages. First, I consider tree canopy as a price determinant in the housing market using a hedonic regression. Subsequently, I measure residents' demand for tree canopy based on their demographic characteristics, which, in theory, are important determinants of demand. I construct a willingness-to-pay (WTP) curve for tree canopy which incorporates the effect of these characteristics.

This leads to my central question: What is the private demand for urban tree canopy throughout Portland, Oregon, and how is this demand distributed with respect to differential levels of tree canopy throughout the city? I will approach the first part of this question using a hedonic regression of property values, quantities of tree canopy, housing characteristics, and neighborhood characteristics, generating an implicit price for tree canopy in Portland. I will then regress this implicit price as a function of demographic characteristics, estimating the relative influence of residential demographics on willingness-to-pay for tree canopy.

In addition to the economic implications of this question, this is also particularly relevant within the framework of urban environmental justice and considerations of equity in access to urban amenities. Urban planners in growing cities face the issue of making quality-of-life amenities accessible to residents in neighborhoods with a lower cost of living, prompting a discussion of what amenities can and should be provided to all residents of a city. Although this paper does not adopt an ethical framework to guide this discussion, it does provide insight into the distribution of urban canopy throughout neighborhoods with varied housing characteristics, as well as local valuation of urban canopy as an amenity. This should prove a useful tool in advancing that discussion.

2 Literature Review

2.1 Determining that Trees have Value

Homeowners have long been interested in the way in which the presence of trees increases the perceived value of a property to homeowners, as evidenced by publications such as Brian R. Payne's "The Twenty-Nine Tree Home Improvement Plan" (1973). This was one of the first articles that attempted to put a dollar value on urban trees. Payne declares that

> The amenities provided by trees in residential neighborhoods are sufficiently sought after to make nurserymen a major influence on the metropolitan landscape. Shade, wind reduction, screens for privacy,

> an environment for wildlife, climbing areas for children, and natural beauty are the motivations behind the annual purchase of veritable forests by American homeowners.

In a short, two-page write-up for *Natural History*, Payne discusses an experiment in which a scale model house was appraised with varying quantities of trees "planted" on the model. As the title implies, he achieved the maximum addition of value with twenty-nine trees on a half acre lot, adding $4,300 to the property value.

This method of comparing similar houses with and without tree canopy continued to pervade attempts to value the influence of trees on residential prices. In 1980, another attempt to quantify the amenity value of trees was published in the Journal of Arboriculture. Dominic Morales' "The Contribution of Trees to Residential Property Value" created pairs of sixty houses with "comparable" structural characteristics and compared those with and without substantial tree cover. A multiple regression was also used to control for variables available from the town assessor. Within this framework, the author determined that "good tree cover" added $2,686 (or 6% of total value) to the property's value in this town (Manchester, Connecticut). However, no mention is made of the variance within this sample, and it is unclear whether these numbers bear much external validity. It does, however, represent an early determination that trees have measurable value to individual properties within the context of the housing market.

In a similar attempt was made by the US Forest Service in 1987, when Anderson and Cordell published "Influence of Trees on Residential Property Values in Athens, Georgia." They focus on the inclusion of trees in the landscaping of a property, and whether that increases the sale price of that property. Anderson and Cordell assess tree canopy with a binary variable, considering only whether or not a property's landscaping includes trees. In doing so, they find that the inclusion of trees in landscaping is correlated with a 3.5-4.5% increase in sales prices.

These studies form a starting point for my investigation, implying that there is a positive relationship between a house's value and the presence of trees on that house's property. Their analysis is limited, however, by the fact that they do not quantify the amount of tree canopy, only its presence or the lack thereof. Additionally, they do not consider possible "spillover effects," where nearby tree canopy which is not on a property itself may still increase the value of that property—a case of external benefits.

I attempt to address these concerns with a hedonic analysis, which breaks down the value of a home into a function of its attributes. In doing so, I consider the proportion of an area covered by tree canopy to contribute to the price of a house, thereby giving an implicit price to tree canopy. An important difference considered in my analysis is the contribution of external benefits. I do so by using the block group as my basic unit of analysis. Although the ideal experiment would use the individual house as the basic unit and address external benefits with a given radius around each property, the block-group method provides a much more feasible and analytically-sound alternative.

2.2 Rosen: The Hedonic Approach

Sherwin Rosen (1974) provides the framework for hedonic analysis in his seminal 1974 paper, "Hedonic Prices and Implicit Markets." This paper connects the utility-maximizing model to the empirical method of estimation, defining the hedonic hypothesis that "goods are valued for their utility-bearing attributes or characteristics." Rosen's model, therefore, begins by considering the value of any good as a function of its characteristics. By measuring the quantity of each characteristic contained in a good, one can calculate the implicit price of that characteristic.

Rosen's theory is based on the idea of product differentiation. This means that for any class of product, there are variations on that product with differing quantities of its characteristics. These varied products also have different prices, as rational consumers operating in a purely competitive market will always choose the lowest-priced product with the highest-valued bundle of characteristics. This implies that marginal changes in one attribute of a good in equilibrium will produce a measurable effect on the price of that good. This effect is the correlation coefficient between a good's price and the quantity of the characteristic of interest, and defines the implicit price of each included characteristic.

Ideally, Rosen's theory could be tested by varying the quantity of one of a product's characteristics, and observing the resultant change in price. However, in the absence of a practical means of performing such an experiment, we can approximate it by observing similar products with differing quantities of that characteristic, controlling for variation in other characteristics.

Therefore, given a sufficient number of products with variable characteristics and different prices, we can compare the variations in product price to the differing quantities of its characteristics, and derive an implicit price for each.

2.3 Applying the Hedonic Method to Residential Amenities

Since its publication, many researchers have applied Rosen's model to valuation of amenities available to homeowners via the housing market. An excellent example was published in the Journal of Urban Economics in March 2015. Yinger's "Hedonic markets and sorting equilibria: Bid-function envelopes for public services and neighborhood amenities" applies a hedonic framework to a number of neighborhood amenities, including educational quality and distance to amenities such as lakefronts and airports. Although his analysis extends Rosen's method to include consideration of the "envelope" of overlap in consumers' bid functions for housing, his method represents a concrete application of the hedonic method in quantifying the value of residential amenities.

Gibbons, Mourato, and Resende also apply Rosen's method to the valuation of many so-called natural amenities in their 2013 paper, "The Amenity Value of English Nature: A Hedonic Price Approach." The authors assess the value to urban settings of nearby habitats, protected areas, urban parks and gardens, and similar amenities. Their analysis is extremely comprehensive, based on the theory that over large geographic areas, the interplay between several amenities of interest may have a non-zero effect on housing prices. In doing so, they consider both the proportion of several amenities located within a given ward (their sampling unit) and the distance to other amenities, such as coastline and national parks. They also control for a large number of potentially significant variables accounting for differential housing prices.

The authors conclude that many of their amenities significantly contribute to house price, especially nearby presence of wetlands, green space, and green belts (a land use policy which aims to retain forested or otherwise "green" areas around the circumference of a city). They report especially high levels of significance for London, suggesting that heavily urban areas may experience an especially high implicit price of open-space amenities. Although their analysis does not explicitly address tree canopy, they provide a useful template for application of the hedonic model.

Li, Saphores, and Gillespie not only apply the hedonic framework, but also use a data analysis method similar to my own in "A comparison of the economic benefits of urban green spaces estimated with NDVI and with high-resolution land cover data" (2014). The authors use hedonic analysis to estimate the value of neighborhood green space, and use an aerial land-cover classification technique to calculate the green space proportions within each of their sample areas (similar to the Maximum Likelihood Classification technique which I discuss in section 4.1). The authors' focus in this paper is on the differing value of their two different resolutions of data which they collect—however, they do establish a correlation between price elasticity of housing and the presence of green space.

In this study, the authors find a weak relationship between housing prices and levels of nearby green space, notably to neighborhood parks. Though they do not provide a calculated implicit price, they do illustrate the value to hedonic modeling of a spatial approach, which intrinsically considers quantities of an amenity as well as its distribution. Their result on which they primarily focus is the value of high-resolution data over moderate-resolution data. Even so, they provide a contemporary example of a technique similar to that which I employ, and use that technique to model the hedonic approach in a way similar to what I accomplish.

2.4 Incorporating Willingness-To-Pay

Rosen's method produces the implicit price of a good's characteristics—that is, how much an increase in the quantity of that characteristic would increase the price of the good. However, if I want to determine the welfare gains to consumers from an increase of the quantity of that characteristic, I need to determine more information about their individual willingness-to-pay (WTP) for that characteristic. On a market scale, WTP for a characteristic is equal to its implicit price. On an individual level, however, WTP is determined by qualities of the consumer. This includes qualities such as income, education, and race. In other words, this asks "Given an implicit price for tree canopy, how much more canopy would a given consumer be willing to purchase given an increase in their income?" Other qualities of residents could, of course, be substituted for income in this statement.

This stage of experimentation is not frequently applied to hedonic analysis, but Kiel and Zabel do something similar in their 2001 paper, "Estimating the Economic Benefits of Cleaning Up Superfund Sites: The Case of Woburn, Massachusetts." Their research uses a hedonic method to consider the value not of an environmental amenity, but of a disamenity: proximity to hazardous waste sites. Their analysis rests on the assumption that a site designated for cleanup on the National Priorities List lowers the value of nearby housing. In this case, the authors estimate consumer's willingness-to-pay for the removal of the disamenity (i.e. the cleanup of the site).

Kiel and Zabel are interested in the amount households would be willing to pay for cleanup of the waste site. In this case, variable distance from the site allows the authors to segment their market and analyze the variable characteristics of each segment. Although Kiel and Zabel do not construct a WTP regression to account for the influence of each demographic characteristic on WTP, their framework could also be applied to include in this way, controlling for the fact that different demographic characteristics may reflect differing levels of WTP for cleanup.

Mahan, Polansky, and Adams, however, do apply the notion of variable willingness-to-pay to a hedonic regression in their 2000 paper, "Valuing Urban Wetlands: A Property Price approach." In the paper, the authors apply a hedonic implicit price analysis similar to my own to estimate the value of proximity to wetland amenities. The authors analyze demand-shift variables in consumers, reflecting the notion that the preferences of the purchaser are theoretically determined by characteristics such as income, age, race, and ethnicity.

The authors segment their market based on distance from wetlands, and conduct a second-stage WTP regression based on a number of demand-shift variables. I will apply a similar method to my analysis, using demographic averages in each block group to determine variable willingness-to-pay. Because this will take the form of a regression of the implicit price of tree canopy on demographic characteristics, this will generalize the influence of each demographic characteristic on WTP as a whole.

3 Theory

My theoretical model is based upon the one presented in Rosen (1974), which is based on utility maximization. The model assumes competitive equilibrium in a many-dimensional space, representing each of n attributes which define a good. In the context of my model, any given house Z can be represented by the bundle of attributes

$$Z = (Z_1, Z_2, ...Z_n), \tag{1}$$

where Z_1 through Z_n measure the quantity of the nth characteristic present in the good. These attributes include structural characteristics, such as square footage and house age, as well as neighborhood characteristics, such as travel time to work and crime rates.

3.1 The Hedonic Price Schedule

In this space, each attribute is valued independently and contributes to the price of the good, $P(Z)$. Because P is a function of all characteristics, a firm must commit resources to the production of additional goods at an increasing rate. Thus, by holding Z_2 through Z_n constant, and by assuming a perfectly competitive market structure, we can draw the relation between P and a given attribute of interest, Z_1, as concave. This defines the Hedonic Price Schedule, shown in Figure 1. Holding other attributes fixed, the slope of this function is the implicit price of Z_1.

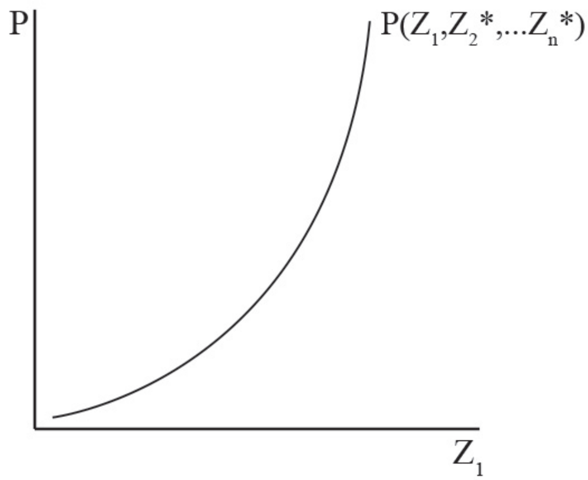

Figure 1: The Hedonic Price Schedule

In the context of my model, therefore, the price of a house can be said to be a function of the quantity of tree canopy on and around its property, in addition to its structural and neighborhood characteristics. By constructing house price as an empirical function of those characteristics, the housing price is made to reveal the implicit price of each of the characteristics.

3.2 The Consumption Decision

In competitive equilibrium, consumers allocate their income so as to purchase a bundle of goods that maximizes their utility. Because of diminishing returns to consumption intensity, moreover, the utility derived from any given good is considered to increase at a decreasing rate. Consumers' indifference curves, which represent the utility tradeoffs between an additional quantity of a given good and an alternative quantity of another good, are therefore convex.

In the context of my model, the aforementioned "goods" are really the attributes of housing in question, and all other goods consumed are defined as the numeraire good, x. By setting the price of the numeraire good equal to unity ($x = 1$), we measure tradeoffs of Z with x in terms of dollars. We can therefore represent a nonlinear utility function as

$$U = U(x, Z_1, Z_2, ...Z_n). \tag{2}$$

Utility therefore depends upon the quantity of each attribute present in the good, increasing at a decreasing rate, as well as on all other goods consumed. Consumers are therefore able to maximize utility tangent to the budget constraint

$$y = x + P(Z), \tag{3}$$

where y represents income, and it is assumed that each consumer only purchases a single house.

We are now able to define a set of willingness-to-pay (WTP) functions, representing consumers' indifference curves with respect to housing characteristics, given that individual consumers have discreet preferences. By measuring income (y) relative to the unity-set numeraire good (x), we can define a WTP function as

$$\theta_i = \theta(Z_1, Z_2, ...Z_n|U, y), \tag{4}$$

showing consumers' preferences for housing characteristics given a level of income and utility. Two of these willingness-to-pay curves, θ, are shown tangential to the Hedonic Price Schedule in Figure 2.

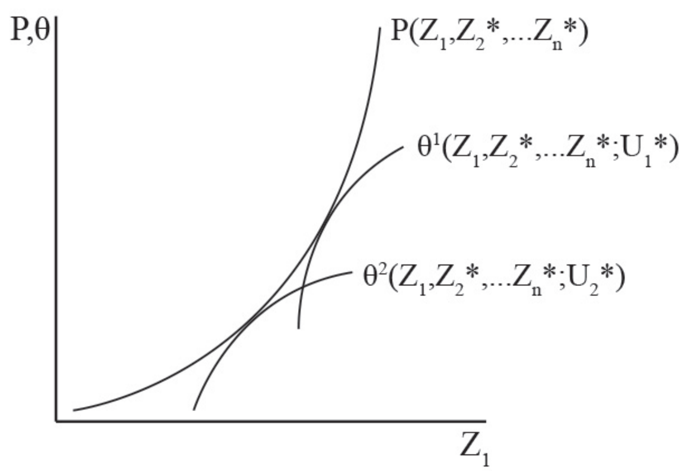

Figure 2: The Hedonic Price Schedule's Tangency to Two Possible WTP Curves

At these tangency points, we can measure the ratio of the marginal utility of Z_1 to the marginal utility of x, or $\frac{MU_{Z1}}{MU_x}$. This defines the marginal rate of substitution. If we assume that markets are in equilibrium, we know that these tangencies represent points of maximum utility, where the marginal rate of substitution between the characteristic in question, in this case Tree Canopy, and all other goods is equal to $\frac{\Delta P}{\Delta Z_1}$, the change in price given a change in Tree Canopy. Allowing for variable preferences with respect to Z, we can construct a number of WTP curves tangential to the price condition. These tangencies, more generally, occur where

$$\frac{\Delta P(Z)}{\Delta Z_i} = \frac{\Delta \theta(Z)}{\Delta Z_i}, \tag{5}$$

indicating that the Hedonic Price Schedule lies tangent to a given consumers' WTP curve (which is an iso-utility curve) at the maximum level of utility. In this model, Z_i is proportional to $\frac{U_{zi}}{U_x}$, and therefore equal to the change in WTP for housing divided by the change in characteristic Z_i.

3.3 Limitations of Model Assumptions

Rosen's model is based on utility maximization theory, where tangencies between consumers' budget constraints and indifference curves maximize the utility gained by their income. This model, however, assumes that consumers have sufficient information to differentiate between all possible allocations of their resources—in other words, it assumes perfect information. This is not altogether likely in the residential housing market, where consumers frequently must spend long periods of time investigating possible options or working with real estate agents in order to generate a satisfactory amount of information to make any decision.

Perfect information is just one feature of the market structure of perfect competition, upon whose presence Rosen's model also relies to guarantee the slope of its curves and to ensure that consumers are able to select the house which allocates their resources so as to maximize utility. Perfect competition, however, is seldom observed in reality, and is certainly not the case in Portland's housing market. Perfect competition would indicate that the good being sold, housing, is standardized with regard to price, and that there are no transaction costs associated with buying or selling a house. In reality and in realty, houses vary widely with respect to the relationship between quality, characteristics, and price. In addition, real estate firms are frequently employed as middlemen in housing sales, adding to the cost of the transaction. Finally, these same firms exert a substantial amount of control over the housing market, largely through control of the aforementioned imperfect information. In effect, while it is clear that Portland's housing market does not exhibit perfect competition, the degree to it resembles it will affect the validity of the hedonic model.

Finally, Rosen's model also assumes that markets are in equilibrium—that is, that supply and demand for housing maximizes economic surplus for both consumers and producers of housing. In the case of housing, a good whose supply takes significant lag time to respond to demand, equilibrium would be disrupted if demand for housing was unable to meet the available supply (such as a sudden decline in the number of prospective homeowners) of if demand exceeded available supply (such a sudden influx of prospective homeowners). In the case of Portland, the latter is more likely to be the case, as Portland is a growing city that has experienced rapid urbanization. Furthermore, Portland has a constraint placed on its housing supply in the form of an Urban Growth Boundary (UGB), which limits the geographic extent of dense development. While it does not present a hard limit to housing growth, it does create a barrier to development, which some studies suggest has increased housing prices in Portland above equilibrium levels.

4 Empirical Estimation

For my method, I use Portland's American Community Survey (ACS)-defined block groups as my primary unit of analysis. The decision to use block groups was based largely on data availability—however, it also serves to account for the external benefits that a property value experiences from trees that are approximate to it but not on the property itself. I then use a Geographic Information System (GIS) analysis to determine the proportion of each block group covered by tree canopy, using 2012 orthoimagery sourced from the US Geologic Survey. and represent this as a fraction of the total area of the block group. I join this with 2011 ACS demographic data to construct my regressions.

The model I use occurs in two stages. The first is a hedonic analysis of housing price with tree canopy included as the variable of interest, and takes the form

$$ln(HP) = \beta_0 + \beta_1 ln(TC) + \beta_2 Structural + \beta_3 Neighborhood + u \qquad (6)$$

Where $ln(HP)$ is the logarithm of median house price, $ln(TC)$ is the logarithm of Tree Canopy as a proportion of land area, $Structural$ represents characteristics of the property itself, $Neighborhood$ represents characteristics of the location in which the house stands, and u is the error term. This regression gives the implicit price of tree canopy as a function of house price. Because both house price and tree canopy are logged so as to report a percent change, this gives the implicit price in the form of an elasticity—the percent change by which house price would respond to a percent change in tree canopy.

In this stage, I expect to see a positively-sloped relationship between the log of House Price and the log of Tree Canopy. This would indicate that a percent increase in tree canopy is associated with a percent increase in house price. For the Structural and Neighborhood characteristics, I expect a mixture of positive and negative relationships. For example, I would expect a percent increase in house price to associate with an increase in number of rooms or an increase in local school quality, but a percent decrease in house price to associate with an in increase in house age or an increase in local crime rates.

The second stage regression estimates residents' willingness-to-pay for tree canopy based on the implicit price of tree canopy and the demographic characteristics of the residents. It takes the form

$$ln(WTP) = \gamma_0 + \gamma_1 ln(TC) + \gamma_2 ln(MHI) + \gamma_3 Age + \gamma_4 Edu + \gamma_5 Race + v \quad (7)$$

Where WTP represents the implicit price, an additional variable calculated by the coefficient of the logarithm of tree canopy from the first-stage regression multiplied by House Price. $ln(MHI)$ is the logarithm of median household income, Age is the median age of residents, Edu is a set of binary variables indicating the level of education residents possess (e.g. high school diploma, bachelor's degree, master's degree), $Race$ is a set of binary variables indicating resident's reported race and ethnicity, and v is the error term. In theory, these demographic characteristics are important determinants of willingness-to-pay for tree canopy, and serve to differentiate the neighborhoods which would extract the greatest total benefits from an increase in tree canopy.

In this stage, I expect to see a positively-sloped relationship between the logarithm of willingness-to-pay and the logarithm of Tree Canopy, as this would indicate that a greater quantity of Tree Canopy demanded would associate with a greater willingness-to-pay for it. Indeed, the two variables should be highly correlated, as $ln(WTP)$ is constructed using the coefficient of $ln(TC)$ from equation 6. I also expect to see a positively-sloped relationship between WTP and Income, as this would indicate that those with greater ability to pay for Tree Canopy are also more willing to do so. The relationship between WTP and Age, Education, and Race & Ethnicity is harder to predict, and I expect it will have a much smaller magnitude of effect than either of the previous variables. This notwithstanding, they are still a theoretically-important factor of willingness-to-pay for Tree Canopy and necessitate inclusion.

4.1 Data

Completing this analysis required data on several variables. First, I required data on house prices, structural characteristics, neighborhood characteristics, and demographic characteristics. Following that, I would need to join this data to a measure of the tree canopy present in any given neighborhood.

The American Community Survey (ACS) met much of the first data need. In their 5-year assessment, last administered in 2011, the ACS measured median property values, numbers of rooms in structures, travel times to work, and characteristics of residents including age, education, and race & ethnicity. Their data is recorded at the block-group level. While this does not provide as high a level of resolution as individual households would, it was the smallest unit of measurement not considered proprietary information (and therefore the smallest unit of measurement available to me).

The block-group-level resolution has other important implications, however. The most important is the way in which it addresses the possible external benefits of tree canopy, where individual households may benefit from the "spillover effects" of tree canopy that is not on their own property, but in proximity to it. By using the block group as the base unit of analysis, the area surrounding each individual house is already included. One other implication to note is that my individual data points are already averaged values, however, which is what allows for statistics such as a maximum household size of 3.63—this is the maximum average household size for a block group.

Data on Portland's tree canopy were not readily available in a directly analyzable format. As best as I can tell, no one has yet published a data set that details what proportion of each of Portland's block groups is covered by tree canopy. As this measurement represented a cornerstone of my analysis, however, I deemed it essential to acquire, and I used this opportunity to produce the data for myself.

Doing so involved analysis of the United States Geologic Survey (USGS)'s 2012 Aerial Orthoimagery of Portland. This is a set of 2500-square-meter quadrants of high-resolution aerial imaging, adjusted for perspective distortion so as to be the same true-area representation of space that a map would be. I compiled 51 of these orthophotos into a single, massive raster image of Portland-from-above using Geographic Information Systems—ArcGIS, in my case. The resulting raster image is shown in Figure 3, which represents a true-area, high-resolution, imagery data set which approximates Portland city limits.

The next step involved classification of the raster by land cover type, so as to be able to determine what proportion of any given area was covered by tree canopy. Having deemed manual classification infeasible (though not for lack of trying, as those who read my website posts know), I set to work with a Spatial Analytics tool called Maximum Likelihood Classification. This method of analysis uses a signature file of classified training samples to fit each pixel of a raster file to the category in which it most likely belongs. It considers the RGB value of each pixel as well as the pixels around it, and chooses the most likely category of the signature file based on the patterns of pixels in the raster image. By creating a sufficiently representative signature file, I was able to classify Portland's land cover to an extent that, while not perfect, provided an accurate enough representation to enable comparison of different areas based on the amount of canopy each contained. The results are shown in Figure 4.

Having now produced a massive raster file of Portland classified by land cover type, it remained to me to separate these data by block group, quantify them, and join them to the remaining data. I accomplished this with a Zonal Histogram, which separates data into defined zones (in my case, block groups) and counts the number of pixels in each value class. I represented each block group by the number of tree canopy pixels it contained divided by the total number of pixels it contained, giving me a proportion of each block group which was covered by tree canopy. I then joined these data to my remaining data, including another GIS task of sorting crime incidents into block groups to generate a local crime count. At the end of this process, I had a data set suitable for regression analysis. Summary statistics are provided in Table 1.

Figure 3: The compiled raster image of Portland, inset to show detail

Figure 4: The results of Maximum Likelihood Classification, inset to show detail

Table 1: Descriptive Statistics for All Variables

Variable	Observations	Mean	Std. Dev	Min	Max
Property Value ($)	257	351,000	116,000	173,000	875,000
Tree Canopy Proportion	257	0.250	0.0796	0.0370	0.500
Lot Size	257	812	615	44.5	5590
Rooms	257	5.14	1.34	1.4	9
House Age	257	66.5	14.7	12	76
Travel Time to Work	257	25.4	3.94	17.3	42.2
Crime Rate	257	115	200	44.5	5590
Household Income ($)	257	57,600	24,500	10,800	156,000
Resident Age	257	36.8	5.91	20.2	58.3
Household Size	257	2.12	0.405	1.10	3.63
High School Diploma	257	0.930	0.0711	0.651	1
Bachelor's Degree	257	0.506	0.164	0.0935	0.871
Master's Degree	257	0.202	0.108	0	0.542
White	257	0.840	0.133	0.314	1
Black	257	0.0900	0.118	0	0.658
American Indian	257	0.0191	0.0261	0	0.136
Asian	257	0.0617	0.0579	0	0.359
Pacific Islander	257	0.00614	0.0198	0	0.141
Other	257	0.0310	0.0562	0	0.358
Latino	257	0.0734	0.0811	0	0.489

All data reported to three significant figures.

5 Results

The first regression measured house price as a function of Tree Canopy, controlling for structural characteristics of the house as well as neighborhood characteristics. Here, the included structural characteristics are lot size, number of rooms, and house age. The included neighborhood characteristics are travel time to work and local crime rate. The regression employs robust standard errors to account for possible heteroskedasticity in the model. The results are summarized in Table 2.

Table 2: Hedonic Regression of Canopy, Structural, and Neighborhood Variables

Variable	β
Tree Canopy (log)	0.233**
	(0.581)
Lot Size	-0.0000598
	(0.0000366)
Rooms	0.0446
	(0.0190)
House Age	-0.00109
	(0.00135)
Travel Time to Work	-0.0266**
	(0.00451)
Crime Rate	0.000159**
	(0.0000804)
Observations	257
F(6, 250)	14.3
$P > F$	0.00
R^2	0.318

** $p < 0.05$

This regression, notably, shows a significant effect of Tree Canopy upon house price. The coefficient is substantive, indicating that a 1% increase in tree canopy is associated with a 0.233% increase in housing price. At four standard errors from zero, it is also highly significant. These values are substantial, which may be a result of endogeneity due to omitted variables. Though I attempted to include the most important variables, there are certainly a wealth of other measurable structural and neighborhood characteristics that could be included. It is also certainly possible, however, that the observed implicit price of tree canopy is simply larger than expected.

Taking the results at face value, we can determine the implicit price for tree canopy in the statistically average block group. This hypothetical block group has a median house value of $351,000 and a tree canopy proportion of 0.25. Therefore, a 1% increase in tree canopy would add 0.025 to the tree canopy proportion, and increase housing prices by $817.83. This number is high, but not out of line with estimates from previous literature. Recall that Payne estimated that the addition of 29 trees to a half-acre property increased prices by $4,300. Morales' 1980 paper found that "good tree cover" added 6% to values for a total increase of $2,686, and Anderson and Cordell found that landscaping including trees added up to $3,073 to house value in 1985. Although none of these papers deal with percent increases to tree canopy, we should also note that none of these values are inflation-adjusted to compare to 2015. For example, Payne's estimate of a $4,300 increase in value is comparable to $23,700 in 2015 dollars.

Having determined an overall implicit elasticity for Portland, I then constructed a variable for willingness-to-pay from the product of the Tree Canopy (log) coefficient and House Price. I logged this variable and regressed it against demographic characteristics of the residents in each block group. The results are summarized in Table 3.

Table 3: Hedonic Regression of Canopy, Structural, and Neighborhood Variables

Variable	β
Tree Canopy (log)	0.133**
	0.0467
Household Income (log)	-0.100*
	(0.0526)
Resident Age	0.0114**
	(0.00274)
Household Size	0.130**
	(0.0437)
Bachelor's Degree	1.08**
	(0.132)
Black	-0.186
	(0.114)
American Indian	-0.0668
	(0.435)
Asian	-0.329
	(0.229)
Pacific Islander	-0.383*
	(0.514)
Other	-0.595**
	(0.254)
Latino	-0.0891
	(0.217)
Observations	257
F(11, 245)	33.4
$P > F$	0.00
R^2	0.571

** $p < 0.01$, * $p < 0.1$

This table reports how willingness-to-pay for tree canopy varies with characteristics of the residents. The first five characteristics are most notable. All have a significant relationship with WTP—Age, Size, and Bachelor's Degree at the 1% level, Median Household Income at the 6% level. At these levels, a 1-year increase in average resident age would yield a 0.0114% increase in WTP, a 1-resident increase in average household size would yield a 0.130% increase in WTP, and a 0.01 increase in the proportion of residents with a bachelor's degree would yield a 1.08% increase in WTP. These results indicate that a prospective increase in tree canopy would generate the greatest welfare gains in a neighborhood with older residents, larger household sizes, and a higher proportion of residents with a college education.

Income is also a significant determinant of WTP, but its results are somewhat counterintuitive. The coefficient is negative, indicating that a 1% increase in income would yield a 0.0998% decrease in WTP. This is unlikely to represent the reality of the situation, and it is more reasonable to assume that this results from endogeneity in the model. In this case, there is most likely an omitted variable with is correlated with income, willingness-to-pay, and the error term. It is certainly a jumping-off point for improvement to the model.

Nevertheless, these results do much to explain the value of tree canopy to a residential area. The presence of tree canopy is apparently valued substantively by current and prospective homeowners, and contributes as such to the housing market. Note that, as the title of this paper implies, this valuation misses any public value of urban canopy—anything not reflected in the price of housing does not show up in this analysis. Nevertheless, it is reasonable to assume that tree canopy may also have value as a public good—a topic worth further study.

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