A VALUATION OF TREES IN URBAN SPACES

A THESIS

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Abstract

An economic valuation of the importance of trees in an urban environment. Using how amenities affect the change of the size of a population in a city, the amenity of trees will be observed. The focus is on how the amenity of green space specifically influences the percentage change of the population in these cities. The number of trees and the health of an urban canopy makes a positive impact on the livability of a city and is an important amenity when considering the value of property within a city. While the focus is on trees this thesis also looks into other economic variables that could be affecting the change in population to make the regression more holistic. The findings from the regressions show that the healthiness of a city's urban forest can influence the change in the population of that city. Tree's improve the overall "livability" of a city.

ON MY HONOR, I HAVE NEITHER GIVEN NOR RECEIVED UNAUTHORIZED AID ON THIS THESIS

Signature

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<u>Introduction</u>

Trees have many important roles in Urban Spaces, but what is their value? How are they benefiting us? Trees in Urban Spaces not only provide a positive influence from an environmental standpoint, but they also benefit public health in many ways. From an analytical perspective this thesis will look into the economic impact of trees in an Urban Space specifically the impact a healthy Urban Canopy has on a city's population.

From an environmental stance, investment in trees benefit urban areas in various ways. Trees absorb pollutants from the air in the areas they inhabit, improving air quality. This is incredibly important in urban settings because of the high population density creates negative effects on air quality. Trees lower the temperature in cities in several ways, one being trees in urban settings can lower surrounding air temperatures by as much as 4 degrees Celsius. The cooling effect of trees leads to a decrease of the need for air conditioning and lowers energy spent cooling. Not only does the shade provided by trees lower the air temperature surrounding trees, but "water vapor given off through transpiration adds to the cooling influence of trees"[1]. The extensive amounts of concrete in cities tends to lead to issues with flooding. Trees aid from this aspect as well, tree canopies reduce stormwater runoff by 65%[2]. In summary, there are three positive environmental impacts that trees have on urban environments, they are removing pollution, lowering temperature, and mitigating/reducing stormwater runoff.

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[1] Arbor Day Foundation. (n.d.). Celebrating Greener Cities Worldwide. *Celebrating Greener Cities Worldwide*.

[2] Arbor Day Foundation *Celebrating Greener Cities Worldwide*.

Investigating the benefits of trees through the lens of public health, studies[3] show that areas within cities that have more green space have lower crime rates, benefiting the community surrounding the areas that have green spaces and city trees. Trees also benefit human's mental health, facilitating mental restoration, reducing depression, anger, anxiety, mental fatigue, and stress. Green spaces in cities inspire outdoor activity and a healthy lifestyle for citizens of cities. The healthy lifestyle that a green space promotes in turn leads to reduced non-communicable diseases, meaning heart conditions, respiratory problems and diabetes, issues that are incredibly prevalent in the United States. The human impact that trees have makes them an important investment for citizens of cities to consider.

Are the human impacts that trees have and the environmental impact enough to influence investment in trees? Trees in urban spaces clearly benefit humans in a myriad of ways, but what are the economic benefits of trees in Urban spaces? Trees are not inexpensive and require constant maintenance and watering in urban settings, so why invest in trees? It is proven through studies that "for every U.S. dollar invested, there is often a $4–$5 annual return in environmental services"[4] meaning that investment in trees is proven to have a positive return. Why would cities not invest in trees? These studies also prove that green infrastructure is the only part of a city's infrastructure that appreciates in value over time. Having a positive return from investment and appreciating

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[3] Arbor Day Foundation *Celebrating Greener Cities Worldwide*.

[4] Arbor Day Foundation Tree City USA®. (n.d.). Retrieved from https://www.arborday.org/programs/treecityusa/

over time should be enough to drive up the investment in trees, if the improved lifespan and environmental better quality of life was not sufficient.

The most important variable to fully understand this analysis is this concept of canopy cover. If trees within a city are erratically placed as opposed to neatly clumped, the distance disperses the canopy. When trees are clustered there is a larger canopy. The impact of the canopy is much more substantial the denser and the healthier the canopy is. The percentage of canopy cover in a city is inclusive of shade provided by trees. The canopy also decreases stormwater runoff and increases the livability of an environment. The varying temperatures in different cities also impacts the health of trees in the urban environment. Temperature allows us to begin to get a grasp on what the climate of a city is like and look at, potentially, how trees influence an urban environment. Rainfall is a good variant to examine because trees flourish in a city that gets a lot of rainfall. The potential cost of water is an important variable to consider because some cities and some areas of cities hold more wealth than others, meaning maybe some cities/citizens can afford to be watering their trees more frequently and therefore can afford to keep the trees in their area alive and healthy. Finally, location is a necessary variable to consider when thinking about this topic as well because it is a good predictor for the climate, as well as the environment of the city, what the people living in these cities value and what drives them.

In order to analyze different cities, there are many factors of the citizens in the cities and the history of the cities that need to be considered also, not necessarily just the location. The City of Cambridge has historically been an incredibly progressive town.

Cambridge is also a city located in a "well-watered region"[5], meaning water is abundant in the city. Cambridge historically has intellectual luster because of Harvard that has carried on today widely known for the technology enterprises, being software and biotechnology research. Being the progressive town that it is the City of Cambridge is very concerned about their urban canopy and they have several programs to protect and promote their Urban Forest. One of the ways the city tries to get citizens of the city to engage with street trees is by informing them that the cost to water a street tree every day for the full watering season costs less than $2.

Austin values investment into trees because of its climate. The climate of the city is relatively temperate promoting outdoor activities year-round. This well-rounded city is also home to an ethnically diverse population and has claim to a vibrant music scene. The music scene draws in tourism every year with a concert series, Austin City Limits. Austin[6] is the capital of Texas and is known to have the Colorado River flowing through the city. When founded the city of Austin flourished as a trading hub for ranching and farming and the contemporary city manages to continue their economic prowess through a different outlet: manufacturing computer technology and software.

Although Seattle is a city that gets a lot of rainfall annually, the city recognizes the importance of the urban canopy. Seattle[7] is a city located "In a mild marine climate

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[5] Cambridge, C. of. (n.d.). Brief History of Cambridge, Mass. Retrieved February 4, 2020, from https://www.cambridgema.gov/historic/cambridgehistory

[6] The Editors of Encyclopaedia Britannica. (2019, October 22). Austin. Retrieved February 4, 2020, from https://www.britannica.com/place/Austin-Texas

[7] Brief History of Seattle. (n.d.). Retrieved February 4, 2020, from https://www.seattle.gov/cityarchives/seattle-facts/brief-history-of-seattle

that encourages pacific vegetation and abundant natural resources" a good description of the character of the city of Seattle is, "Seattle is proud of its arts and cultural institutions, the many live theatres and the downtown art museum. It is proud of its parks, of its professional and collegiate sports, of Pioneer Square and the Pike Place Market, and, above all, of the beauty of its surroundings"[8].

The city of Tempe[9] is located just outside of Phoenix in a river valley popularly referred to as the Valley of the Sun. Tempe's physical environment is known to have a dry warm climate and less than 8 inches of precipitation annually. Although the city is surrounded by mountains, none are high enough to draw in much moisture making Tempe the driest city included in this study. The way Tempe justifies investment in trees is to keep moisture within the city to improve the health of the overall city.

Chicago[10] is a large city with a lot of wealth, diversity, and history. Chicago focuses a lot on their Urban Canopy and the public trees that are in the city. Traditionally in the city there has always been a focus and emphasis on the physical infrastructure of the city which could explain the large number of trees the city has today.

A Healthy Urban Canopy in the city of Houston is essential mostly because of the proximity to the ocean. Houston[11] is an inland port city on the Gulf of Mexico. The city

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[8] Brief History of Seattle

[9] McNamee, G. L. (2019, May 17). Phoenix. Retrieved from https://www.britannica.com/place/Phoenix-Arizona

[10] "Encyclopedia of Chicago," Encyclopedia of Chicago, accessed February 11, 2020, http://www.encyclopedia.chicagohistory.org/)

[11] The Editors of Encyclopaedia Britannica. (2019, November 29). Houston. Retrieved February 4, 2020, from https://www.britannica.com/place/Houston

has a very warm, humid climate and is known for “it's hot sticky summers”[12]. Having this hot sticky climate and being so close to wetlands makes Houston prone to floods, the Urban Canopy helps to mitigate this. Houston is one of the largest cities being looked at in this analysis. It is a pretty progressive city.

Literature Review

Other studies[13] have been done observing what amenities or goods are drivers for humans to locate to different “neighborhoods” or areas within cities. When you have competing packages of goods what are the goods that motivate you to move to a specific area? “These models take individual households’ residential location choices as the target of analysis and using the logic of Tiebout sorting recover estimates of preferences for spatially varying levels of quasi fixed goods”[14] Similar to this study this Thesis analyzes the drivers that cause people to move in and out of different cities. The amenity that is focused on in this thesis to see if it is a significant driver for people to relocate is the health of the Urban Canopy in a city, is it enough to cause humans to relocate?

The benefits of trees in urban spaces are extensive and the literature on this topic proves this through various cases. One of the ways that trees benefit urban spaces is by

[12] The Editors of Encyclopaedia Britannica *Houston*

[13] Klaiber, H. Allen, and Daniel J. Phaneuf. "Do Sorting and Heterogeneity Matter for Open Space Policy Analysis? An Empirical Comparison of Hedonic and Sorting Models." *American Journal of Agricultural Economics* 91, no. 5 (2009): 1312-318. Accessed February 11, 2020. www.jstor.org/stable/20616301.

[14] Klaiber, H. Allen, and Daniel J. Phaneuf. *Do Sorting and Heterogeneity Matter*

lowering emissions from air conditioning and cooling. In 2015 a study[15] was done on the Cooling and energy saving potentials of shade trees and urban lawns in a desert city. It was found in this study that 47.6% of the energy produced every year in the United States is used building. A large percentage of this building is occurring throughout cities in the United States. With the growth that the United States is experiencing in cities we are increasing the amount of asphalt and concrete in cities which only contributes to the excessive waste and heat release experienced in cities. The increase in building is only contributing to the environmental issues experienced in cities. More building leads to more issues from the Urban Heat Island effect, air quality degradation, and human thermal discomfort. One of the ways to reduce the stress put onto the environment by all of the building occurring in cities throughout the United States is to increase the vegetation in urban environments as well. The study continues then to discuss the energy saving potentials of green spaces in urban settings and the research that was taking place on this topic in previous decades. They found that "previous studies have shown that homes with shade trees in cooling dominant cities can save over 30% of residential peak cooling demand"[16] proving that shade trees can reduce energy spent on cooling. In this study they were observing Phoenix Arizona. They chose to study the effect of the energy saving potential of trees in Phoenix for two main reasons. One of the reasons they chose to study Phoenix was due to the fact that Phoenix had experienced extensive urban expansion over the previous decades. Undergoing this expansion made Phoenix an area

[15] Zhi-HuaWang. (2015, October 22). Cooling and energy saving potentials of shade trees and urban lawns in a desert city. Retrieved February 4, 2020, from https://reader.elsevier.com/reader/sd/pii/S030626191501274X?token=EF6752BC

[16] Wang *Cooling and energy saving potentials*

of interest to study because cities that undergo expansion over a short period of time tend to be cities that are susceptible to Urban heat islands and become areas of urban environmental interest. The second reason they chose to study Phoenix was because of the location of the city, because it is a city located in a desert and therefore has a high need for cooling. The study used the radiative shading of trees and the heat rays from urban surfaces to understand the effect of shade trees in this environment. The study found that shade trees were effective in cooling the environment that they were located in. The study was also able to convert the reduced energy, that was provided by the cooling of tree shading, into monetary savings using the local electricity price. The study was then able to conclude that urban vegetation had a direct relation to the cooling of urban environments and that urban vegetation holds significant energy saving potential.

A study[17] on the Economic valuation of urban forest benefits was done in Finland in 2001. The study begins by discussing how narrowly defined financial aspects have previously dominated the discussion of urban development, which makes sense because in the short term building quickly and cost effectively has a higher return. The article then continues to discuss the environmental quality of urban development, and the importance of green areas in urban environments to humans. A survey was conducted to understand the citizens of Finland's willingness to pay to keep green space in urban environments and a separate survey to understand the willingness to pay to create more green space in urban spaces. The study split the benefits of green spaces into 5 categories to understand the citizens attitudes towards urban forests. The categories being: economic,

[17] Tyrväinen, L. (2002, May 25). Economic valuation of urban forest benefits in Finland. Retrieved February 4, 2020, from https://www.sciencedirect.com/science/article/pii/S0301479701904219

architectural, climate, social, and nature, and they found that most people thought the biggest benefit from green spaces were the nature and social impact of the spaces. They also found from the survey that the majority of citizens saw no negative impact from urban green spaces, meaning most citizens believed these spaces have value. The study also found that the majority of citizens would be willing to pay a monthly fee for the use of forested recreation areas and that citizens would also be willing to pay to prevent the reduction of forested areas, meaning that they would be willing to pay to prevent construction and building in forested areas. After analyzing the results of these surveys this study was able to conclude that "the monetary benefits of urban forests are much higher than the present maintenance costs"[18] meaning that the benefits or urban forests outweighed the costs from the perspective of the citizens of Finland. The study also concludes saying "in an urban setting, people are more accustomed and ready to pay for their leisure time and therefore payments for outdoor recreation are probably more acceptable than in other forest areas"[19]. So, not even considering the environmental benefits and from the citizens of cities viewpoints alone, forested areas have importance and economic value to humans. This study took place in Finland, but a conjecture could be made that the same conclusion would be arrived at had the study been done in the United States.

[18] Tyrväinen, L. *Economic valuation of urban forest benefits in Finland*

[19] Tyrväinen, L. *Economic valuation of urban forest benefits in Finland*

A study done in the United Kingdom[20] looked at the effect of tree shade and grass on surface and globe temperatures in an urban area. The study discusses how built surfaces, meaning, asphalt, concrete and bricks, which are surfaces found in urban environments absorb more heat than vegetated surfaces. These surfaces which absorb more heat leads to Urban Heat Islands and heat related illnesses among humans. The study then continues to talk about vegetated areas and the three-dimensional cooling nature of trees, reducing surface temperature underneath them, and the air temperature in the surrounding space. The study was able to conclude after examining temperatures of areas of shade from trees and areas of direct sun in an urban setting that tree shade was very capable of lowering local air and global temperatures, which both greatly affect human comfort and in the long run with more trees lowering temperatures would lower the cost of cooling in cities.

Many cities across the United States have recognized the importance of having a healthy tree canopy throughout the city. Since recognizing the importance of the tree canopy in their cities, many of these cities have been making strides to improve and increase the tree canopy percentage in the city. One city that has recognized the importance of their tree canopy is the city of Tempe. Tempe is a city in the United States, located just east of Phoenix, Arizona that wants to have a public health focused infrastructure that cools the streets, cleans the air, mitigates the effects of global warming and beautifies the city, this is why Tempe is so concerned with their urban forest.

[20] Armson, D., Stringer, P., & Ennos, A. R. (2012, June 15). The effect of tree shade and grass on surface and globe temperatures in an urban area. Retrieved February 4, 2020, from https://www.sciencedirect.com/science/article/pii/S1618866712000611

Tempe's Urban Forestry plan[21] outlines what the city's urban forest looks like currently and how they plan to improve their urban forest in the future. The city is working to improve the city's urban forest through three influences on the public of the city. The first way that the city is reaching out to the public to improve the urban canopy is by educating the citizens of Tempe. Tempe offers education to the public through community workshops and training in forestry. As well as education the city is trying to involve the public in collaboration to improve the urban forest. They are including the public by developing public and private partnerships, working with county, state, and federal agencies as well as tapping into ASU for research and collaborative programs such as the sustainable cities network. The final way the city is engaging the public is through implementation. The city of Tempe launched a community-based tree planting program, they expanded existing tree programs including grants and they established a volunteer tree team in the city. Currently Tempe is at 13.4% canopy cover with 19,450 city-managed trees. Tempe acknowledges the economic benefits that come with a healthy Urban Forest and they are working to improve the canopy cover in the city. They found that an increase in canopy cover "from 0% to 10% decreases average neighborhood temperatures by 3.6 degrees Fahrenheit; increasing the tree canopy to 25% leads to an additional temperature reduction of 4.3 degrees Fahrenheit a total cooling benefit of 7.9 degrees Fahrenheit"[22].The city also found that they yearly economic benefits of the existing tree canopy was $1,399,065. This monetary value was found by looking at the

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[21] "The City of Tempe Urban Foresty Master Plan." Tempe. The City of Tempe. Accessed February 11, 2020. https://www.tempe.gov/government/community-services/parks/urban-forest/urban-forest-master-plan.

[22] "The City of Tempe Urban Foresty Master Plan." Tempe

benefits of trees on stormwater, air quality, carbon, energy usage and aesthetic/other. Another aspect of trees that is important to highlight is the DBH, or the diameter at breast height, the economic benefits of trees increases at a higher DBH. This is because trees with a larger diameter tend to have a larger canopy, making them more valuable to the city. Issues the city has run into with implementing their goal is a lack of education that the citizens of the city currently have. Another issue that they have run into is a human issue with trees, citizens who own small businesses don't want trees blocking their signs and citizens of the city get bothered by the debris that trees can leave, leaves falling branches dying, etc. The city of Tempe concludes their analysis of their Forestry master plan stating that, "The metrics for success lies in developing a deeper understanding of the benefits provided by urban trees and a public and private commitment to allocating the necessary resources to achieving a healthy and sustainable urban forest"[23].

The city of Cambridge in Massachusetts also has a strong interest in their urban forest and urban canopy. Cambridge has been making strides to increase their urban canopy as well as keeping well documented records of the trees in the city, paying attention to how different species are growing and tracking the progress of the trees in different neighborhoods and the overall tree canopy. Having these records and maintaining detailed accounts of the trees allows the city to manage their urban forest. One way the city improves their urban canopy by paying attention to the tree census they have is understanding that trees are susceptible to different diseases. The city makes note of that and makes sure to not plant these trees in close proximity to one another, so

[23] "The City of Tempe Urban Foresty Master Plan." Tempe

disease is less likely to spread. “Each new tree costs the city $320 for shade trees and $344 for ornamental trees, which includes the purchase price, installation and a one-year warranty on the tree. Three hundred new trees planted over two planting seasons, spring and fall, can cost nearly $100,000”[24].Understanding the cost of the trees that they are planting throughout the city encourages Cambridge to keep these detailed records and focus on the health of the trees in the city, because once they are planted and begin to grow their value only increases until they die and are removed.

Cities such as Cambridge and Tempe understanding the importance of their cities Urban Forest is extremely important, and many other cities throughout the United States recognize the importance of their Urban Canopy and are making similar strides to maintain and grow their Urban Forest. How exactly do these trees positively benefit the cities they are in from an economic standpoint? How does the canopy size affect the cost of energy use in the city in the summer? How do the trees improve the cities wealth? Using the tree census’ for many cities throughout the United States this thesis will analyze the economic benefit of maintaining trees in cities.

Economic Theory

In previous studies done evaluating green space in Urban Environments the value of green space was analyzed by observing the human willingness to pay. This analysis of the value of green space will do something similar to Tiebout. Tiebout sorting looks at

[24] Ciesielski, L. The Trees of the City of Cambridge: An analysis of the City’s Street and Park Trees, The Trees of the City of Cambridge: An analysis of the City’s Street and Park Trees (2011). Retrieved from https://www.cambridgema.gov/~/media/Files/publicworksdepartment/urbanforestmasterplan/20111219treesofthecityofcambridgedpw.pdf

the goods in a neighborhood and analyzes how they affect movement into different neighborhoods. This analysis will look at the change of the population in cities and see if the amenity of trees is a significant driver of the change in population in these cities. Looking at other economic variables that influence change in population size and seeing how they affect the change of population size will demonstrate clearly how trees interact with the population change. The initial regression equation is as follows:

$$Y_i = B_0 + B_1(\text{Unemployment}) + B_2(\text{CostofWater}) + B_3(\text{ElectricityExpense}) + B_4(\text{Trees})$$

where the dependent variable is the Change in Population in each city. Based on my understanding an increase in Unemployment will decrease the change in population, the livability of the city decreases as unemployment rises. Therefore, the unemployment rate in the city should have a negative correlation with the Change in Population in the city. The Cost of Water in the cities have a negative correlation with the Change in Population in the city, the more expensive the water costs should be a negative impact on the livability of the city and outmigration should increase. If Electricity Expense increases, I would expect the change in population to decrease, meaning Electricity expense should be negatively correlated to increase in population size. The Tree Variable is a combination of the canopy coverage, the total trees, the summer temperature and the summer and winter precipitation in those cities. I expect the tree variable to have a positive correlation with the change in population size.

Data Description

To analyze the economic benefits of trees in urban environments, I will be looking at tree census' from several cities across the United States. Looking at the tree census' will allow me to see how many trees they have currently planted in their city and will help to gain an understanding of how trees in cities are affecting the cost of energy in the cities in different climates across the United States. The six cities I will be focusing on are: Tempe, Cambridge, Austin, Houston, Seattle, and Chicago. After obtaining tree census' from all of these cities I will begin to look at the benefit of trees in their cities by looking to see if larger canopy sizes throughout cities can be predicted by rainfall, temperature, cost of water, and electricity costs. The variable Change in Population is the change from the year 2017 when Canopy Coverage data was obtained to today. Summer Temperature is the Averaged temperature from the Summer months and Winter Temperature is the average temperature from the Winter months. Canopy Coverage is the % of the cities square footage that is covered by canopy when using LiDAR (light detection and ranging). Summer and Winter Rainfall are the average precipitation in inches from each of the cities. Unemployment is the most recent unemployment rate from each of the cities. Cost of water is the city's water and sewer rates annually in US dollars. The Electricity Expenditure variable is a combination of the industrial, commercial and residential electricity expenditure annually in $10,000,000.

The Tree Variable is a combination of the canopy coverage, the total trees, the summer temperature and the summer and winter precipitation in those cities. The canopy coverage, the total trees, the summer and winter precipitation will all be multiplied together because the total number of trees in the cities is positively related to the canopy coverage as well as precipitation, these will all be divided by the summer temperature. They will be divided by the summer temperature because the Canopy Coverage is negatively affected by the summer temperature.

Summary statistics: N, mean, sd, min, max

Cambridge

Variable	Obs	Mean	Std.Dev.	Min	Max
TotalofTrees	439	510453.8	2429370	1	4.43e+07
CostofWater	439	76.4139	7.896101	64	91.4
ElectricityExpenditures	439	36.97631	12.29296	24	53
Unemployment	439	4.015535	1.013096	2.28	5.4
Change in Pop.	439	3.133303	1.313485	.93	4.9
Tree Variable	439	2.96515	1.400745	1	5.36

Austin

Variable	Obs	Mean	Std.Dev.	Min	Max
TotalofTrees	439	510453.8	2429370	1	4.43e+07
CostofWater	439	76.4139	7.896101	64	91.4
ElectricityExpenditures	439	36.97631	12.29296	24	53
Unemployment	439	4.015535	1.013096	2.28	5.4
Change in Pop.	439	3.133303	1.313485	.93	4.9
Number of Trees	439	2.96515	1.400745	1	5.36

Tempe

Variable	Obs	Mean	Std.Dev.	Min	Max
TotalofTrees	439	510453.8	2429370	1	4.43e+07
CostofWater	439	76.4139	7.896101	64	91.4
ElectricityExpenditures	439	36.97631	12.29296	24	53
Unemployment	439	4.015535	1.013096	2.28	5.4
Change in Pop.	439	3.133303	1.313485	.93	4.9
Tree Variable	439	2.96515	1.400745	1	5.36

Chicago

Variable	Obs	Mean	Std.Dev.	Min	Max
TotalofTrees	165	952377.2	2429370	1	4.43e+07
Costofwater	165	3.98	7.896101	64	91.4
ElectricitryExpenditure	165	36.97631	12.29296	24	53
Unemployment	165	4.015535	1.013096	2.28	5.4
Change in Pop.	165	3.133303	1.313485	.93	4.9
Tree Variable	165	2.96515	1.400745	1	5.36

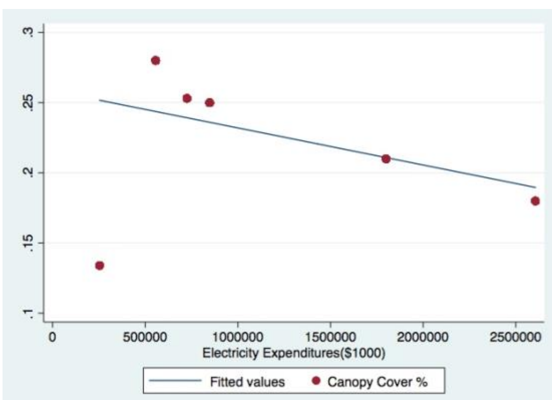
Houston

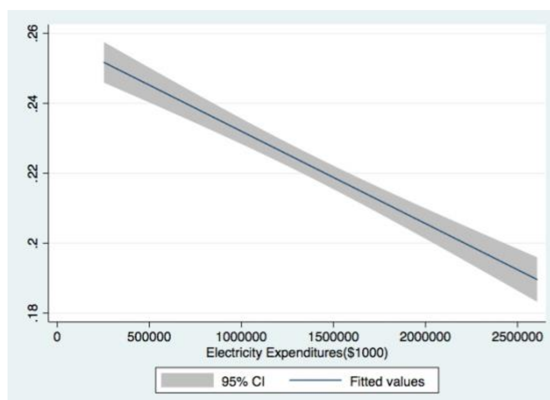
Variable	Obs	Mean	Std.Dev.	Min	Max
TotalofTrees	62	536544.5	1241988	11740	7610442
CostofWater	62	5.17	0	5.17	5.17
Electricity Expenditures	62	2606	0	2606	2606
Unemployment	62	3.6	0	3.6	3.6
Change in Pop.	62	1	0	1	1
Tree Variable	62	622030.5	1.17e-10	622030.5	622030.5

Average summary statistics across all Cities

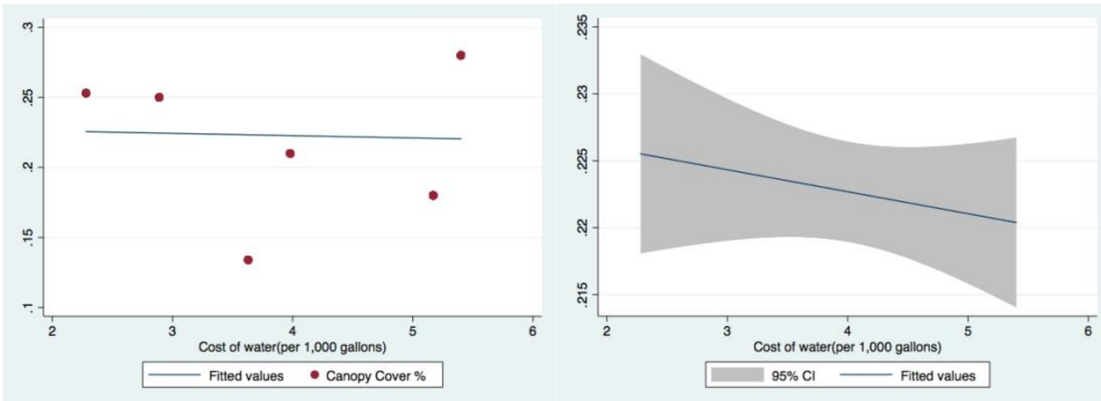
Variable	Obs	Mean	Std.Dev.	Min	Max
TotalofTrees	439	510453.8	2429370	1	4.43e+07
SummerTemp	439	76.4139	7.896101	64	91.4
WinterTemp	439	36.97631	12.29296	24	53
CostofWater	439	4.015535	1.013096	2.28	5.4
SummerRainfall	439	3.133303	1.313485	.93	4.9
WinterRainfall	439	2.96515	1.400745	1	5.36
ElectricityExpenditures	439	1353.609	749.582	253.809	2605.985
Unemployment	439	3.063781	.4995297	2.1	3.8
Change in Pop.	439	.6241458	.4848953	-34023	67092
Number of Trees	439	6.86e+07	7.00e+07	0	1
Tree Variable	439	1124819	1136793	55.03456	2559174

<u>Results & Interpretations:</u>

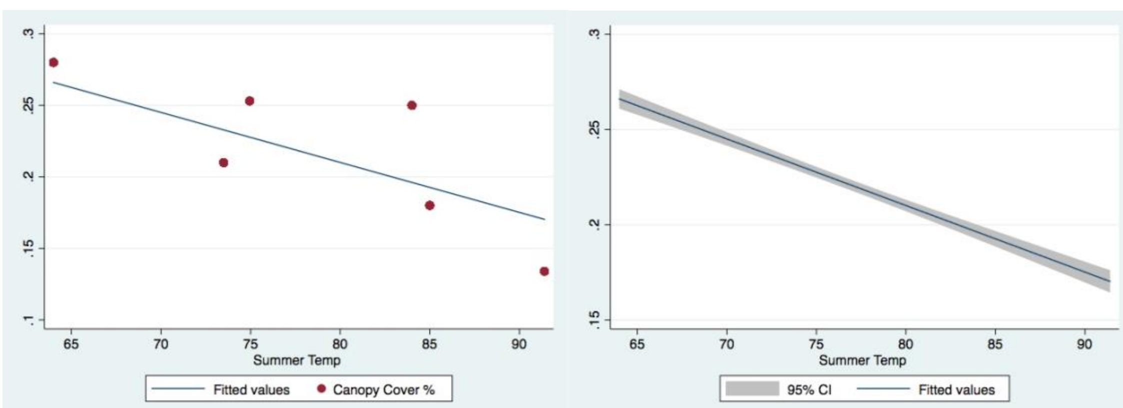




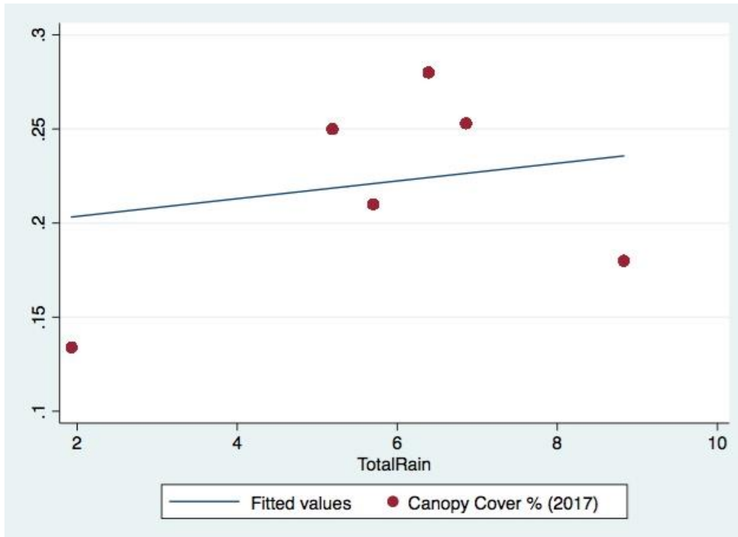
These graphs display the negative relationship between Canopy Cover and Electricity Expenditure, as the Electricity expense increases there is a decrease in the size of the overall canopy within the city except for one outlier, Tempe. Tempe has a small Urban Canopy but also low Electricity Expenditures. Tempe is a desert city that could use urban lawn space to add to the green space in their city and this could account for their lack of Urban Canopy. Overall what is being observes from these graphs is the Urban Canopy decreases as Electricity Expenditures increase.



These graphs display that there is a slight negative correlation between the Canopy Cover percentage and the Cost of water. This means that city's with lower water costs observe a larger Urban Canopy, but not always. This result makes sense because the more expensive water is the less likely water will be used to water trees, a healthy urban canopy is not a necesity to life.



These Graph show a negative relationship between the Summer Temperatures in the cities and the Canopy Coverage, meaning the higher the temperatures the harder it is to maintain an urban canopy. The higher the heat is in a city will lower the canopy coverage observed in that city.



This graph displays that there is an overall positive correlation between total rainfall in the cities observed and canopy coverage. This is important because this displays the postive correlation between rainfall and a healthy Urban Forest. When considering the health of trees in an Urban Setting, rainfall is a very improtrant variable.

The initial results from running the regression on the percentage change in the population by the tree variable were as follows:

Number of obs	439
F(1, 437)	0.05
Prob > F	0.8165
R-squared	0.0001
Adj Rsquared	-0.0022
Root MSE	.48542

Source	SS	Degrees of Freedom	MS
Model	.012697873	1	.012697873
Residual	102.971357	437	.235632395
Total	102.984055	438	.235123412

PopChange	Coef.	Std. Err	t	P>|t|	95% Conf. Interval

TreeVariable	2.39e-08	1.03e-07	0.23	-0.817	-1.79e-07, 2.27e-07
_cons	.61794	.0353752	17.47	0.000	.5484133 , .6874667

This regression showed a small sum of sqaures for the model and had a large amount of error. The large p value means the null hypothesis cannot be rejected and the tree variable is not a good predictor of the change in population in this model. The R squared value observed here also shows that this is a bad model.

After running this first regression there was a clear issue with the difference in the total number of trees in each city. The size difference between some of the cities I was looking into was significant and that the smaller cities had significantly less trees in their cities than the larger cities. Using this significant size differential the data was broken up by city size and the regression was run again.

Seattle, Cambridge and Tempe were grouped together because they are all cities of similar sizes, but they all observe very different climates and environments. This is the result from regressing the tree variable on the change in population for the smaller cities, the smaller cities being Seattle, Cambridge and Tempe:

Source	SS	Degrees of Freedom	MS
Model	1184.9374	1	1184.9374
Residual	81.5188341	147	.554549892
Total	1266.45623	148	8.55713672

Number of obs	149
F(1, 437)	2136.76
Prob > F	0.0000
R-squared	0.9356
Adj Rsquared	0.9352
Root MSE	.74468

PopChange	Coef.	Std. Err	t	P>|t|	95% Conf. Interval
TreeVariable	.0010567	.0000229	46.23	0.000	-1.79e-07, 2.27e-07
_cons	2.099488	.0880006	23.86	0.000	.5484133 , .6874667

The sum of squares observed in this model show that there is small error in this model, the small p values show that the tree variable is a good predictor of the change in population and the high R squared value means this model has a strong fit.

Similar to the choice to group together Seattle, Cambridge and Tempe, the larger cities: Austin, Chicago and Houston were grouped together as well. These three cities are similar in size but observe completely different climates. This is the result from regressing the tree variable on the change in population for the larger cities, the larger cities being Chicago, Houston and Austin:

Source	SS	Degrees of Freedom	MS
Model	2013.27168	1	2013.27168
Residual	1251.65316	288	4.34601791
Total	3264.92484	289	11.2973178

Number of obs	290
F(1, 437)	463.25
Prob > F	0.0000
R-squared	0.6166
Adj Rsquared	0.6153
Root MSE	2.0847

PopChange	Coef.	Std. Err	t	P>|t|	95% Conf. Interval
TreeVariable	.0000166	7.71e-07	21.52	0.00	.0000151, .0000181
_cons	-5.10590	.3251713	-15.7	0.000	-5.745915 , -4.465888

The sum of squares observed in this model show that there is small error in this model, the small p values show that the tree variable is a good predictor of the change in population and the high R squared value means this model has a strong fit.

After breaking up the data by city size the new regressions were giving a better fit for the data. The regression was run again but adjusting for this difference of size and making the larger cities total number of trees in 10,000 so they would be weighted about the same as the smaller cities when running the regression.

When the data was adjusted for the difference in size of the cities the regression was run again but with the new data obtained:

Number of obs	439
F(1, 437)	325.05
Prob > F	0.0000
R-squared	0.4265
Adj Rsquared	0.4252
Root MSE	2.7695

Source	SS	Degrees of Freedom	MS
Model	2493.17564	1	2493.17564
Residual	3351.85997	437	7.67016011
Total	5845.03561	438	13.3448302

PopChange	Coef.	Std. Err	t	P>|t|	95% Conf. Interval
TreeVariable	.0011777	.0000653	18.03	0.000	.0010493, .001306
_cons	1.478496	.1465108	10.09	0.000	1.190542, 1.766449

The sum of squared residuals observed in this regression are much higher than the sum of squared residuals observed in the initial regression of the data meaning that this regression has less error observed and is a better model. The small p value means that we can reject the null hypothesis that the tree variable is not a good predictor of the percent change in population. The positive coefficient assosciated with the tree variable means that the tree variable and the percent change in the population are positively corellated and therefore people are chosing to move to cities that posses a healthy tree environment. The R squared value shows that this variable is a good predictor of the change in the population in each city but could be improved by adding more variables to the model.

After running the initial regression of just the tree variable on the change in population Unemployment was added to the regression and the results were as follows:

Source	SS	Degrees of Freedom	MS
Model	2932.42053	2	1466.21026
Residual	2912.61508	436	6.68030982
Total	5845.03561	438	13.3448302

Number of obs	439
F(1, 437)	219.48
Prob > F	0.0000
R-squared	0.5017
Adj Rsquared	0.4994
Root MSE	2.5846

PopChange	Coef.	Std. Err	t	P>|t|	95% Conf. Interval
Unemployment	-2.03466	.2509218	-8.11	0.000	-2.527834, -1.541501
TreeVariable	.0010919	.0000619	17.65	0.000	.0009703, .0012135
_cons	7.795232	.7909089	9.86	0.000	6.240764,9.3497

Adding Unemployment to the regression increased the sum of squares for the model meaning that this regression has less observed error than the previous regression. The low p values observed for Unemployment and the Tree variable means that the null hypothesis can be rejected for these two variables and say that these variables are related to the percent change in population. The negative coefficient for the Unemployment variable is logical for the model because it displays Unemployment is negatively correlated with the change of the population in the cities, people aren't chosing to move to cities when higher rated of unemployment are observed. The increase in the R squared value means that the model was improved from the previous regression by adding the unemployment variable to the model.

By adding the Cost of water in the cities to the regression the following results were obtained:

Source	SS	Degrees of Freedom	MS
Model	2934.76702	3	978.255673
Residual	2910.26859	435	6.69027262
Total	5845.03561	438	13.3448302

Number of obs	439
F(1, 437)	146.22
Prob > F	0.0000
R-squared	0.5021
Adj Rsquared	0.4987
Root MSE	2.5866

PopChange	Coef.	Std. Err	t	P>|t|	95% Conf. Interval
Unemployment	-2.30608	.5225829	-4.41	0.000	-3.333185, -1.278982
CostofWater	.185828	.3137788	0.59	0.554	-.430883, .8025391
TreeVariable	.0010259	.0001276	8.04	0.000	.0007751, .0012766
Cons_	7.944493	.8306567	9.56	0.000	6.311893, 9.577097

Looking at these results the sum of squared residuals went up from the previous regression that had been run meaning adding the variable for the cost of water in each city improved the overall regression and decreased the error obeserved in this regression. The low p values observed for Unemployment and the Tree variable means that the null hypothesis can be rejected for these two variables and say that these variables are related to the percent change in population. The high p value observed for the cost of water in each city means that the null hypothesis for this variable cannot be rejected and therefore it cannot be said that the cost of water affects the percent change in the population. The increase in the R squared value means that the model was improved from the previous regression by adding the cost of water, and the variables in the model are good predictors of migration in cities.

Adding Electricity Expenditures to the regression the following results are obtained:

Number of obs	439
F(1, 437)	4990.98
Prob > F	0.0000
R-squared	0.9787
Adj Rsquared	0.9785
Root MSE	.5353

Source	SS	Degrees of Freedom	MS
Model	5720.67277	4	1430.16819
Residual	124.362841	434	.286550324
Total	5845.03561	438	13.3448302

PopChange	Coef.	Std. Err	t	P>|t|	95% Conf. Interval
Unemployment	-18.0219	.1926169	-93.5	0.000	-18.40051 , -17.64336
CostofWater	17.79381	.1900183	93.64	0.000	17.42034, 18.16728
Electricity	-.013535	.0001373	-98.6	0.000	-.0138049, -.0132653
TreeVariable	-.007241	.0000879	-82.3	0.000	-.007414, -.0070685
Cons_	11.70824	.1760965	66.49	0.000	11.36214, 12.05435

There appears to be an issue with collinearity between Electricity Expenditures and the cost of water in this regression, although all p values are showing the null hypothesis is rejected for all variables the changing coeficients leads one to believe that adding Electricity Expenditures to the regression skewed the results.

Running the model with Electricity Expenditure instead of Cost of water the following results were obtained:

Source	SS	Degrees of Freedom	MS
Model	3207.92965	3	1069.30988
Residual	2637.10596	435	6.06231254
Total	5845.03561	438	13.3448302

Number of obs	439
F(1, 437)	176.39
Prob > F	0.0000
R-squared	0.5488
Adj Rsquared	0.5457
Root MSE	2.4622

PopChange	Coef.	Std. Err	t	P>|t|	95% Conf. Interval
Unemployment	-.959744	.2873358	-3.34	0.0001	-1.524484, -.3950056
Electricity	-.001454	.0002158	-6.74	0.000	-.0018787, -.0010305
TreeVariable	.000876	.0000671	13.06	0.000	.0007751, .0010079
Cons_	6.679755	.7713933	8.66	0.000	5.163634, 8.195877

The sum of squared residuals is the highest observed without an issue of collinearity. The p values for all of the variables are small meaning the null hypothesis can be rejected for all of these variables and the coeficient for the Tree variable remained positive while the coeficient for unemployment remained negative, both agreeing with the initial hypothesis. The coefficient for the electricity expenditure is negative, meaning there is a negative correlation between electricity expenditures and the change in the population which agrees with the initial hypothesis. The R squared value is also the highest observed without an issue of collinearity.

Conclusion

The analysis that has been undertaken has looked at the impact of various attributes of trees in an urban environment and the contribution they give to the in change of a poulation within cities. The conclusion of this thesis will analyze each of the attributes: the Ordinary Least Squares regression used to analyze the impact, the meaning of the variables values, and further studies that could be done. The Final regression equation obtained is as follows:

$$Y_i = B_0 + B_1(\text{Unemployment}) + B_2(\text{Electricity Expenditures}) + B_3(\text{Trees})$$

This regression equation is the best regression equation obtained because it had the highest observed Sum of squares for the model, meaning the least error, and the highest observed R squared value without an issue of collinearity. The variable for the Cost of water in each city was dropped because it had a relatively large p value, meaning the null hypothesis that cost of water did not affect the change in population could not be dropped and therefor this variable was not significant. The cost of water variable was also dropped because there was an issue of collinearity.

This regression equation also had p values for all variables, meaning the null hypothesis that these variables did not predict the change in population in the city can be rejected, and the coefficients for all of these variables agreed with the initial hypotheses.

It is incredibly important to really look in depth at the coefficients attatched to the variables after the regression results and really understand what is going on here. The coefficient attatched to the Unemployment variable fit the model and the hypothesis assosciated with this variable. Having a negative coefficient meant that the unemployment variable had a negative relationship with the percent change in the population. As unemployment decreases the change in population increases. The hypothesis here being that people will not want to move to a city with high unemployment and the regression result backs up this hypothesis. The value this coefficient has is -0.959 the highest observed coefficent value. Meaning unemployment is one of the strongest predictors of the change in the population size of a city. As unemployment decreases at a rate of .959 the population grows. Cities with a lower unemployment rate are observing the most growth.

The electricity expenditure also had a negative coefficient which fits the model and the hypothesis, similar to the unemployment variable. As electricity expenditure decreases the population increases. The hypothesis being that people will not want to move to an area with high electricity expenditures because this lowers the overall "livability" of this area. Electricity Expenditure has a coefficient at -0.0014546. As the Electricity Expenditure decreases at a rate of -0.0014546 the percent change in the population increases. Electricity Expenditures were weighted in the data to be more on par with the other variables being analyzed in this regression. The Electricity Expenditure variable is actually in terms of $10,000,000. The knowledge of the weighting of this variable is important when looking at this coefficient because it shows how much weight that coefficient actually carries.

The tree variable coefficient from the regression agrees with my hypothesis and fits the model also. Tree's from all aspects of human life increase the "livability" of a space for humans. Trees lower potential costs, as well as increasing health and comfort. The better the trees the more desirable the location, so the higher the tree variable in a city the more people will populate that area. The tree variable coefficient is very small at

.000876. What this coefficient means is as the tree variable increases at .00876 the change in population is increasing also. The observed coefficient for the tree variable being this small makes sense because although trees have positive health, and environmental benefits, trees are not a necessity to life. This variable has lesser weight than both electricity expenditure and unemployment and this makes sense because if you are unemployed or not making enough money to pay bills in a city you have to move, whereas trees are an expense that improve quality of life if you can afford them.

One variable that was left out that could have possibly changed or influenced the results from the regression would be adding urban lawn data to the regression. Desert cities use urban lawns to add to the green space in their city and this data was not considered in this regression. Adding a variable for urban lawns could have improved the overall results had this been added.

If another change was to be made to this regression the first thing to do would to be to find more cities to be observed. Increasing the number of cities going into this model could add more variation to the data and different results could potentially be observed. Although the cities that were looked at in this regression span the United States and are all cities of different sizes looking at less developed cities or comparing wealthy and poor cities in the United States could have been interesting.

Due to the fact that the Cost of water was found to be collinear another variable could have been added to this regression. A potential variable to add to this regression would be looking into the political stances in the cities observed and seeing if the majority of the citizens of the city have a certain political leaning, wether that it the majority of the citizens are republicans or democrats and seeing if that affects the change in the population of the city. Another potential variable that could have been added to this regression would be how much money the average individual in each city is willing to spend on health insurance. The more money that an individual is willing to spend on life insurance, likely this person cares more about their overall quality of life, or has more money to influence where they choose to live.

The findings from the regressions show that the healthiness of a city's urban forest can influence the change in the population of that city. Tree's improve the overall "livability" of a city. Trees are an important amenity when considering the overall health of a city, they are found to have a positive effect on the change of the population in a city.

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