SPATIOTEMPORAL PATTERNS OF URBAN TREE CANOPY AND ENVIRONMENTAL EQUITY IN ATLANTA

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SPATIOTEMPORAL PATTERNS OF URBAN TREE CANOPY AND ENVIRONMENTAL EQUITY IN ATLANTA

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To my amazing wife Haeseung,

for providing me with unfailing support

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SUMMARY

With growing concerns about climate change, the benefits of urban tree canopy has gained a significant attention, leading to various efforts aimed at increasing urban tree canopy. Because urban tree canopy is often considered as environmental amenity, past studies in the field of environmental equity have established that urban tree canopy is often unevenly distributed across the socioeconomic spectrum, favoring those with higher socioeconomic status who can outbid others. An increase in urban tree canopy can attract higher socioeconomic classes, allowing the neighborhood-sorting to occur in a longitudinal manner. Many of the past studies used cross-sectional models to examine the relationship between the distribution of urban tree canopy and socioeconomic status of residents, and the understanding of the longitudinal relationship has been limited.

In addition to the environmental equity, this study adds the vulnerability theory into the research framework. In vulnerability theory, human vulnerability is defined as a function of exposure, adaptive capacity, and sensitivity. The urban trees are known to be effective risk moderator, and socioeconomic/demographic indicators have been frequently used as proxies of adaptive capacity and sensitivity, together providing a pathway to bridge the uneven distribution of urban tree canopy and their benefits to the vulnerability theory.

Based on this research framework, this study examines the longitudinal relationship between residential tree canopy and socioeconomic status in Atlanta between 2000 and 2013. Using census data and two remote sensing datasets, two cross-sectional spatial regression models are developed for 2000 and 2013, and one longitudinal spatial regression for the period of 2000 to 2009.

The findings suggest that in 2000, socioeconomic indicators used in environmental equity and vulnerability, such as the proportion of racial minority and poverty rate, generally supported the existence of inequity in Atlanta. The longitudinal model between 2000 and 2009, however, indicates improvements for some of these indicators. Most notably, the higher percentage of African-American and Asian population in 2000 and an increase in poverty rate is associated with an increase in residential urban tree canopy. An increase in the percentage of residents with bachelor's degree or higher is associated with a decrease in residential tree canopy. There is an interaction effect between the change in the percentage of African-American and the change in the poverty rate. The 2013 cross-sectional model shows that the higher proportions of African-American and Asian are associated with higher tree canopy. However, economic disadvantages – the poverty rate and the proportion of renters – remains as significant predictors of environmental inequity.

This study illustrates the importance of a longitudinal perspective in better understanding the relationship between urban tree canopy and socioeconomic status. Policy suggestions aimed at providing urban tree canopy in more equitable ways and reducing the vulnerability gaps are made.

CHAPTER 1. INTRODUCTION

Cities are the heterogeneous mixture of desirable and undesirable land uses. The geography of various land uses is shaped by complex dynamics of factors including demographic and socioeconomic characteristics of individuals or communities. These factors translate into differential levels of resources with which residents realize their preferences for living environments. Intuitively, residents with higher socioeconomic status tend to have more economic and political resources to attain neighborhoods that meet their preference or to prevent undesirable land uses and facilities to be built in their neighborhoods. Despite the fact that a healthy environment is a basic human right (UN, 1992), past studies in the field of environmental equity have established that various land uses shaping unhealthy environment are not evenly distributed across the socioeconomic and demographic spectrum (UCCCRJ, 1987; Sheppard et al., 1999; Bullard, 2000).

More recent studies on environmental equity have been broadened their attention to incorporate not only the uneven distribution of undesirable land uses but also *desirable* land uses such as urban tree canopy (Landry and Chakraborty, 2009). Tiebout's local public goods theory suggests that residents decide where to live based on the levels of amenities in a neighborhood and the extent to which they match their ability to pay (Tiebout, 1956). Preferable factors such as urban tree canopy in a community would attract those who can afford the amenity, sorting out those who cannot. Residents with different levels of resources and advantages (or disadvantages) can thus have unequal chances of translating their preferences for the healthy environment into actual neighborhood attainments. Proliferating studies have confirmed that urban trees provide ranges of benefits to urban residents but these benefits are disproportionately enjoyed by higher socioeconomic classes (Landry and Chakraborty, 2009).

Urban trees are an important environmental amenity providing numbers of benefits to urban residents. With the growing concerns about the impact of climate change, urban trees are increasingly regarded as a critical infrastructure, especially for those who are more vulnerable to the environmental hazards. Efforts to maintain the existing urban trees and to plant new ones are becoming a pervasive goal, frequently included in municipal initiatives for sustainability and climate change adaptation or mitigation (Danford et al., 2014; Schwarz et al., 2015). For example, the Atlanta Climate Action Plan acknowledges that urban trees provide critical benefits such carbon sequestration, temperature reduction, and energy conservation, and remarks that increasing tree canopy is the city's primary focus (City of Atlanta 2015, 40).

What is less clear, however, is how increase or decrease in urban tree canopy over time is related to the improvement (or degradation) of environmental equity. Studies on environmental gentrification suggest that when an undesirable land use or a facility is introduced to a neighborhood, residents of higher socioeconomic status tend to move to other neighborhoods that better match their preferences and resources, and those of lower socioeconomic status move in (Eckerd 2011). Conversely, when a favorable amenity is introduced to a neighborhood, it is likely that the benefits from the amenity will be disproportionately enjoyed by those who can outbid others. Furthermore, higher socioeconomic classes may also have more political means to prevent the introduction of unwanted land uses into their neighborhoods and can foster an introduction of desirable amenities. These neighborhood sorting and the resultant inequitable redistribution of amenities and disamenities by socioeconomic classes occurring in a longitudinal manner may reinforce the existing inequity. If the increase or decrease in urban tree cover is associated with socioeconomic shifts, the benefits of urban tree cover may flow to people with higher socioeconomic status (Eckerd 2011; Wolch et al., 2014). Because the majority of previous studies on the equitable distribution of urban tree canopy have used cross-sectional models, understandings on this longitudinal trend have been limited. The patterns of inequity observed at a given point in time may be on a path towards even higher inequity, stabilization, or reduction of inequity. Additionally, there has been an influx of middle- and high-socioeconomic classes in the inner city which has altered the demographic and socioeconomic landscape of Atlanta. The understanding of the influence of this trend on environmental equity has been limited.

Thus, this study attempts to fill this gap by examining patterns of the equitable distribution of urban tree canopy at multiple time points and analyzing its longitudinal trend in the city of Atlanta. In a formal form, this study attempts to answer the question: How does the change in tree canopy relate to the change in the socioeconomic status of residents? Based on the environmental equity and environmental gentrification hypothesis, this question generates two hypotheses: (1) an increase in urban tree canopy may be associated with an improvement in socioeconomic status of the residents, and (2) an improvement in socioeconomic status of the residents may be associated with an increase in urban tree canopy. In doing so, this study first lays out a research background by examining the past findings on the relationship between urban tree canopy and environmental equity, and vulnerability theory. Second, methods utilized to test the hypotheses are delineated. Third, the results of the analysis on the longitudinal patterns of urban tree canopy, the changing landscape of socioeconomics, and the statistical examination of the relationship between them are explained. Finally, this study concludes with the implications of the results and policy recommendations.

CHAPTER 2. RESEARCH BACKGROUND

2.1 Research Framework

This study examines the relationship between urban tree canopy and socioeconomic indicators from the perspective of environmental equity. In addition to the environmental equity, the vulnerability theory is also incorporated into the theoretical framework based on the growing relevance of the benefits of urban tree canopy to the impact of climate change. As shown in figure 1, the relationship between urban tree canopy and socioeconomic/demographic indicators are closely linked with the environmental equity framework and vulnerability theory. Thus, this section first examines the past findings on urban tree canopy and environmental equity. Then the benefits of the urban tree canopy, its implications to climate change, and efforts for preservation are described. Lastly, the vulnerability and how it relates to the goals of this study is delineated.

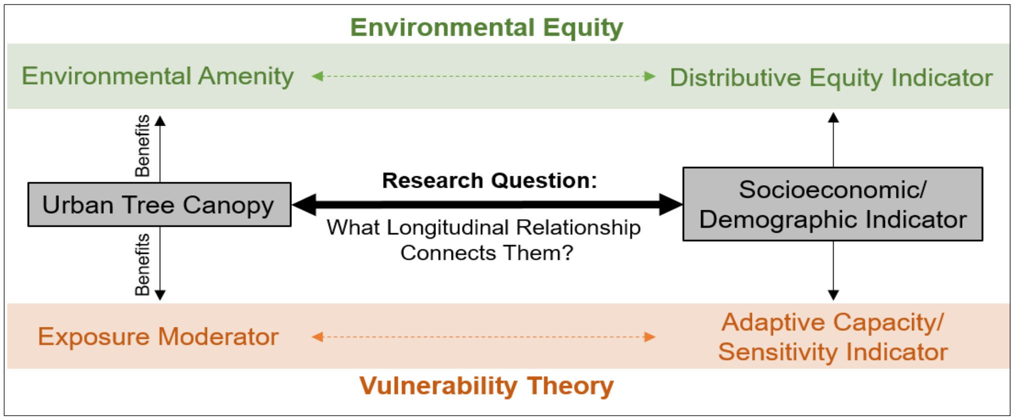

Figure 1. Theoretical Framework of the Study

It is important to note that this study does not argue for causal relationships between the changes in urban tree canopy over time and the changes socioeconomic/demographic geography. While from the perspective of environmental gentrification it is the improvement or degradation of environmental quality of a neighborhood that induces gentrifications, an up-shifting or a down-shifting in socioeconomic status of the residents, there also exist studies indicating that different socioeconomic, cultural, and racial groups have varying levels of resources, motivations, and interests for the plantation of new trees and the maintenance (Heynen, Perkins, and Roy (2006). Thus, this study focuses on asserting associative relationships between the distribution of urban tree canopy and geography of socioeconomic statuses.

2.2 Urban Tree Canopy and Environmental Equity

Past studies have documented that the distribution of urban trees and their benefits tend to be disproportionately enjoyed by affluent, well-educated people who are likely to be non-minority (Landry and Chakraborty 2009; Wolch et al., 2014; Schwarz et al., 2015; Krafft and Fryd, 2016). Landry and Chakraborty (2009) examined how urban trees on residential parcels as well as street trees are related to socioeconomic indicators in the City of Tampa, Florida. Using series of cross-sectional spatial regression models, they found results that support the inequity hypothesis in which lower socioeconomic statuses are expected to have a lower share of urban trees. Indicators of socioeconomic status that were statistically significant include median household income, the share of renters, the proportion of African-American ($p < 0.05$), and proportion of Hispanic ($p < 0.1$). In

Milwaukee, Heynen, Perkins, and Roy (2006) found that median household income and the proportion of non-Hispanic Whites are associated with greater canopy cover, and the percentage of renters, vacancy, and Hispanic are in negative association with canopy cover. A study by Krafft and Fryd (2016) is one of a few longitudinal study on urban tree-related environmental equity. In five Local Government Areas within inner Melbourne, they examined how socioeconomic status, including median household income, home ownership, and the number of university graduates, in 2001 is related to canopy cover in 2011. Using rank order correlation and descriptive statistics comparing socioeconomic status in 2001 and canopy cover in 2011, they found that former income is the strongest precursor of future tree cover, followed by the number of university graduates and home ownership.

A group of studies used hedonic models to estimate the contribution of the abundance of or proximity to tree canopy to property values. They generally found positive contributions of tree canopy to property values (Morales, 1980; Anderson and Cordell, 1988; Tyrväinen and Miettinen, 2000). A study by Sander, Polasky, and Haight (2010), found that the higher residential tree canopy contributes to higher property value and the degree to which the tree canopy affects the housing property value varies depending on the buffer distance from parcels. Using Ramsey and Dakota Counties, Minnesota, as study sites, they measured the contribution of tree canopy to property price by incrementally increasing buffer distance from 100 meters to 1,000 meters from parcels. The result indicated that tree canopy within 100 and 250-meter buffer contributed higher sales value, and beyond that point tree cover is associated with lower sales value. Although some of these studies were conducted to verify that benefits of urban tree canopy increase the desirability of housing properties and therefore increase demand for such properties, their results can be interpreted as urban tree canopy may have a negative effect on the affordability.

However, despite the general agreement among researchers on the existence of inequity, their findings on the effect of race/ethnicity varies. Using scenario-based analysis and population projections, Danford et al. (2014) found that economically disadvantaged neighborhoods are associated with less tree cover, but the association between minority neighborhoods are weakly related to increased tree cover. They stated, "…in the city of Boston low income seems to be a more significant Environmental Justice indicator than minority status (p. 14)." Schwarz et al. (2015) examined the distributional equity of urban trees in seven cities across the United States that have various social and biogeophysical characteristics. They found strong positive correlations between urban tree cover and median household income but varying levels and directions of correlations between race and urban tree cover. The negative effect of racial and ethnic minorities was found only in Californian cities of Sacramento and Los Angeles where maintenance of urban tree canopy requires additional resources for irrigation. Similarly, Pham et al. (2012) found inequity in the distribution of vegetation in Montreal, Canada, which disserved people of low income and, to a lesser extent, minorities. The findings of Troy et al. (2007) is even more contrasting; they noted a positive relationship between the percentage of African-American and urban vegetation in Baltimore, Maryland. These inconsistencies in findings, particularly with race, indicate that the socioeconomic status and urban trees may relate to each other in different ways depending on each city's unique characteristics and that there may be stratification within a racial group that are manifested in differential residential choices. These discrepancies exist even after controlling for income levels. Table 1 shows a summary of findings from past studies.

Table 1. Characteristics known to have association with urban tree cover

Category	Variable	Effect
Socioeconomic	Median household income	Positive/Inconclusive
	Median housing value	Positive
	Minority status	-
	Percent African American	Negative/Positive
	Percent Asian	Inconclusive
	Percent Hispanic or Latino	Negative
	Percent non-White	Negative
	Housing ownership	Positive
	Educational attainment	-
	Percent of high graduates	Positive
	Percent of bachelor's degree holder	Positive
	Poverty	-
	Percent under poverty line	Negative
Demographic	Median population age	Positive
	Life stage	-
	Average household size	Positive/Inconclusive
Urban Form	Land use mix	Negative
	Density/residential density	Negative/Inconclusive
	Street connectivity	Positive
	Street density	Negative
	Median block perimeter	Insignificant
Housing	Median building age	Positive
	Median building age^2	Negative
	Parcel size	-
	Size of parcel	Insignificant

(Source: Troy et al., 2007; Landry and Chakraborty, 2009; Lowry, Baker, and Ramsey, 2012; Pham et al., 2012; Jesdale, Morello-Frosch, and Cushing, 2013; Danford et al., 2014)

2.3 Benefits of Urban Forest and Efforts for the Preservation

The importance of the past studies on environmental equity partly stems from the significant benefits urban tree canopy provides to the residents. These benefits include provision of clean water, improvement in air quality and reduced respiratory-related morbidity and mortality, building energy conservation through shading and cooling, microclimate regulation which in turn reduces heat-related morbidity and mortality, storm water runoff managements, increased physical activity, reduction in crime and many other environmental and social benefits (Benedict and McMahon, 2006; Nowak and Greenfield, 2012; Donovan et al., 2013).

Due to these benefits, urban trees have been receiving attention as an effective adaptation and mitigation strategy for climate change and its impact on urban residents. As the impact of climate change has intensified enough to transition from ambiguous projections to the actual experience in recent years, there has been a growing awareness and detailed documentations of the impact of climate change. In the Southeast region of the United States, the average annual temperature has increased by 2°F between 1970 and the present (Carter et al., 2014). According to National Climate Assessment conducted by U.S. Global Change Research Program, the region has seen an increasing number of days above 95 °F and nights above 75 °F, and this temperature is anticipated to rise during this century (Carter et al., 2014). Considering the significant heat-related mortality (Stone et al., 2014), the trend of warming temperature can be an alarming public health concern. Some large cities in Georgia, Florida, and Louisiana has already seen an increase in the number of hot days, during which mortality is above the average (Sheridan, Kalksterin and Kalkstein, 2009). Accordingly, policy makers and planners are acknowledging the importance of having urban trees in their cities and neighborhoods, which is resulting in numerous tree canopy assessments throughout the country (see, for example, City of Atlanta, 2014). Climate change is expected to increase the frequency and intensity of extreme weather events, for many of which urban tree canopy is known to be an effective mitigation (Stone, 2012).

Furthermore, the loss of tree canopy in urban areas often translates into a gain in impervious surfaces. It means such conversions not only lead to a mere reduction in benefits but also an increase of adverse impacts from the urban materials such as urban heat island effect. Urban heat island effect refers to the development of higher temperatures in urbanized area compared to the temperatures of surrounding rural areas (Santamouris, 2013). It is caused by the transition of land cover from forest and agricultural to urban land uses and alters land-atmosphere energy balance relationships (Quattrochi and Luvall, 1999). These urban materials are often dark in color, impervious, and have large heat storage capacity, all of which are contributing factors to urban heat island effect (Oke, 1967; Stone, 2012). Extreme heat events intensified by climate change can be further exacerbated by urban heat island effect and the combination can render urban residents particularly more vulnerable. Urban trees are an effective way to counteract to urban heat island effect. The presence of urban trees increases the level of evapotranspiration, an effective moderator of near-surface climates (Taha, 1997). Brian Stone (2012) argues "among the full suite of conceivable approaches to cooling urban environments, none is more effective or less energy intensive than planting trees." He further argues that "a doubling of the region's forest cover … could reduce temperatures on the hottest days by more than 12°F." Another example of extreme weather events to which urban tree canopy can be an effective moderator is flooding. The extreme precipitation in the U.S. is showing an upward trend (Walsh et al., 2014). Heavier rain can cause the greater percentage of rainfall to run off and, depending on the land cover, can lead to more flooding (Walsh et al., 2014). Trees can reduce storm water run-off by intercepting the rainfall before it hits the ground, functioning as a temporal storage, and absorbing it through their roots (Seitz, 2011). According to a simulation for Santa Monica, CA, trees intercepted 1.6% of the total precipitation annually, which translated into $3.60 of avoided stormwater treatment and flood control cost per tree (Xiao and McPherson, 2002).

Despite these well-established benefits of the urban tree canopy, Atlanta, a city with the reputation for its abundant urban tree canopy, has been rapidly losing its tree canopy. With around half of the city area covered in trees, Atlanta is one of the most densely forested cities in the U.S. (Nowak and Greenfield, 2012). However, a study by Nowak and Greenfield (2012) found that there has been a statistically significant decline in tree canopy in 19 U.S. cities including Atlanta between 2005 and 2009. The rate at which Atlanta is losing its urban tree canopy is relatively fast; it ranked fifth among the 19 cities in terms of the percentage of urban tree canopy lost between 2005 and 2009. Every year, roughly 150 hectares of tree canopy has been lost in Atlanta (Nowak and Greenfield 2012). In a longer timeframe, Atlanta metropolitan area has lost 25% of urban tree canopy since 1973 (Benedict and McMahon 2006).

To protect urban trees in Atlanta, city officials in 1977 crafted an ordinance requiring developers to either replace the trees they remove or pay into a compensation fund, which is used by the city to support tree planting efforts (American Forests, accessed April 22, 2016). This ordinance was amended in 1995, 2001 and 2002 to reflect the faster pace of developments over the last two decades and to broaden the protection of the city's trees (Ibid). Atlanta's Tree Protection ordinance sets to achieve the goals of 'no net loss' of trees and to establish and maintain maximum tree cover on public and private lands within the boundaries of the city. In doing so, the ordinance prohibits destruction and removal of trees by requiring a permit application to the City Arborist Division for any tree of 6 inches or greater in diameter at breast height (DBH). Any processes of construction, renovation, demolition, landscaping, and other purposes involving tree removal require a permit (Sec. 158-101). In a case where the removal is allowed, the ordinance sets a recompense strategy which is attained either by "in-kind" planting of the replacement trees or by "in-cash" payment into a Tree Trust Fund. Homeowners and builders are required to replant an equal number of trees on site to replace those removed where the replacement trees shall be over-story (>80' at maturity) or mid- canopy (60-80 at maturity), or understory or ornamental depending on site condition (Sec.158-103(a)). When all the replacement trees cannot be accommodated on site, the opportunities of off-site plantations to local parks, public lands, and along right-of-ways are provided for remainder trees. The replanting of the replacement trees is required within the same Neighborhood Planning Unit (NPU) district or within one-mile buffer from the NPU boundary, where the relocation sites are prioritized for areas in need of soil stabilization such as steep slopes, banks of wetlands, and waterways or areas that have physical environmental conducive to the development of heat island effect. The "in- cash" recompense is made according to the formula:

Recompense = $100 (number of trees removed – number of trees replaced)

+ $30 (total diameter inches removed – total caliper inches replaced).

Furthermore, for new subdivisions, new lots of record, and vacant lots, a maximum recompense standard is set at a prorated per acre basis by zoning classification. The ordinance also allows a provision of reducing the maximum recompense payment through replanting when the minimum trees to be retained is met. The ordinance also seeks to mitigate increasing impervious surface by requiring plantation of shade trees in parking lots and along the streets where appropriate. A total of 30 or more parking spaces requires at least ten percent of the landscaping of the total paved area within such lot and minimum of one tree per eight parking spaces.

Despite its stringent regulations, the policy has been criticized for its limitations in increasing urban tree canopy even when a full enforcement is assumed. Stone (2012) argues that the ‘no net tree loss’ goal of Atlanta’s tree protection ordinance may not be helpful in increasing urban tree canopy above its baseline of status quo. The Tree Trust Fund also has not been successful: more than 15,000 tree removals permitted each year far exceeds the replantation supported by Atlanta’s tree trust fund (Stone, 2012). The regulation mandating the replacement of removed trees in a NPU must be made within or near the same NPU may be hindering the tree protection ordinance from having an additional function of redistributing the urban tree canopy within the city. The tree canopy assessment for the city of Atlanta (The City of Atlanta, 2014) showed that the urban tree canopy in Atlanta has a significant variation within the city boundary, with NPU L, M, and

V having the least urban tree canopy. These NPUs are at the center of the city area containing the downtown and neighborhoods in proximity to Downtown and have medium to low socioeconomic status (Botchwey, Guhathakurta, and Zhang, 2014). The current tree protection ordinance alone is limited to induce new tree plantations in these NPUs, and these NPUs may need to rely heavily on other initiatives for tree plantation.

Fortunately, there has been efforts to increase urban tree canopy outside of the regulatory mechanisms. The Trees Atlanta, for example, has planted more than 113,000 trees across Atlanta since its foundation in 1985 (Trees Atlanta, Accessed on March 11, 2017). Supported by donations from multiple resources, the Trees Atlanta was originally focused on urban tree canopy in the downtown area and has expanded the scope to the entire city (Ibid). The locations of tree plantation have been effectively allocated in areas with low urban tree canopy and areas that can be characterized by low socioeconomic statuses (figure 2). The organization also provides services for conservation (e.g., maintenance, forest restoration, and invasive species removal) and education.

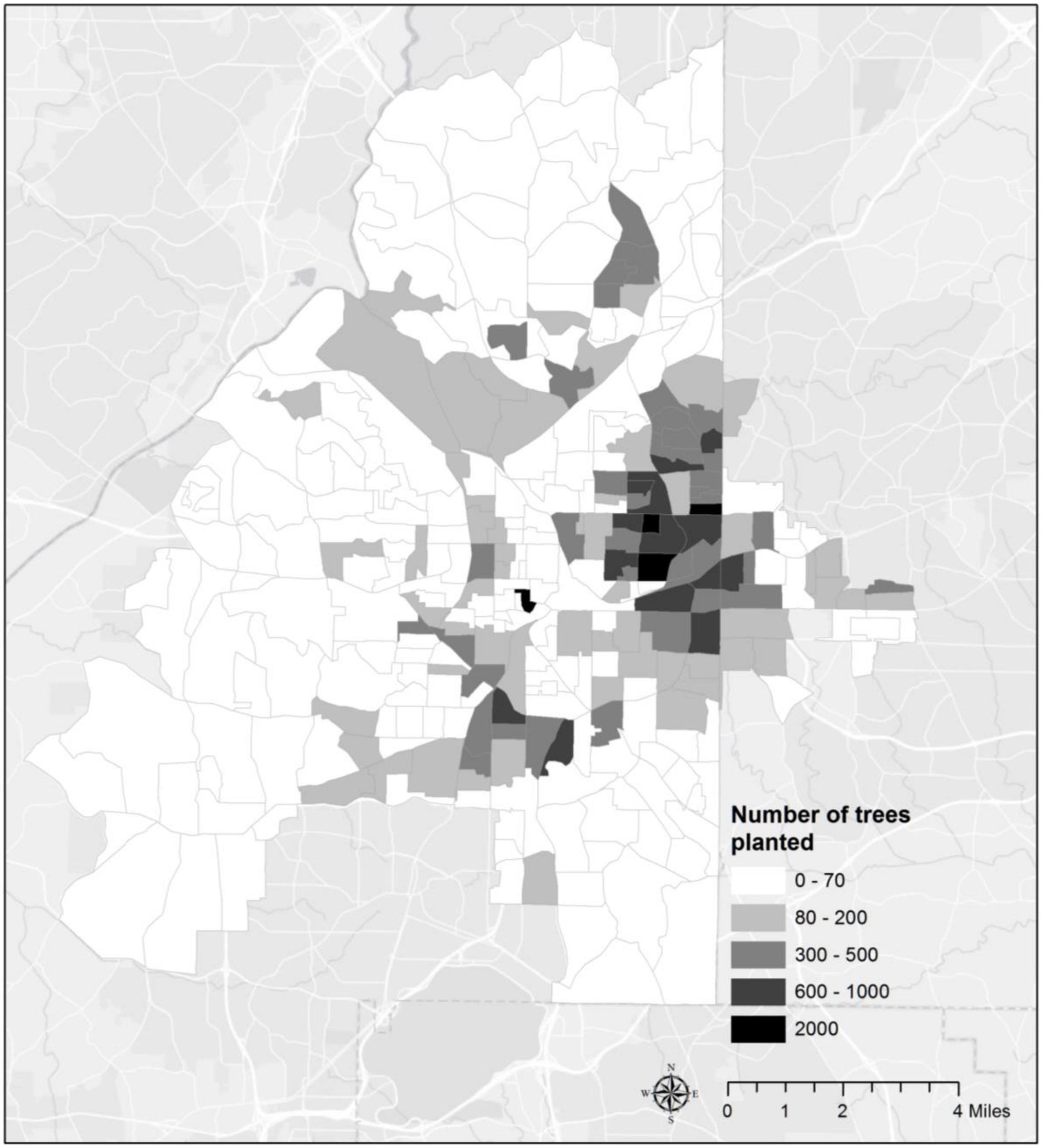

Figure 2. The Locations and numbers of Trees Planted by Trees Atlanta between 2000 and 2010

2.4 Urban Tree Canopy and Vulnerability Theory

The efforts for the preservation and plantation of urban tree canopy with a sufficient consideration of the environmental equity can be particularly important because populations with lower socioeconomic status and of racial/ethnic minorities often have a higher level of vulnerability to the impacts of climate change. The vulnerability of human to environmental hazards is defined as “the degree to which they are likely to experience harm due to exposure (Chow, Chuang, and Gober, 2012).” In detail, past research defined human vulnerability as a function of exposure, sensitivity, and adaptive capacity (Turner et al, 2003; Gallopin, 2006; Polsky, Neff, and Yarnal, 2007; Karner, Hondula, and Vanos, 2015). Sensitivity can be characterized by a range of individual factors that put certain populations at risk when the exposure is experienced (Karner, Hondula, and Vanos, 2015) such as age or pre-existing medical conditions. The adaptive capacity refers to the ability to mitigate the risk of harm from the exposure through adaptive means such as air-conditioning, access to cooling centers, landscaping, and other similar mechanisms (Chow, Chuang, and Gober, 2012). Sensitivity and adaptive capacity have been viewed to have close relationships with various socioeconomic/demographic characteristics (Ngo, 2001; Mayhorn, 2005; Chow, Chuang, and Gober, 2012; Wolf and McGregor, 2013). Cutter and Finch (2008) write, “race/ethnicity, socioeconomic class, and gender are among the most common characteristics that define vulnerable populations, along with age (elderly and children), migration, and housing tenure” (p. 2301). In short, age, gender, race, and socioeconomic status are widely viewed as acceptable characteristics to construct vulnerability indices to environmental hazards (Cutter, Boruff, and Shirley 2003). Regarding the relationship among sensitivity, adaptive capacity, and exposure, Smit and Wandel (2006) write, “generally, a system (e.g. a community) that is more exposed and sensitive to a climate stimulus, condition or hazard will be more vulnerable, ceteris paribus (all other things being equal), and a system that has more adaptive capacity will tend to be less vulnerable, ceteris paribus (p. 286).”

The variables used to construct sensitivity and adaptive capacity largely overlaps with the variables commonly utilized in environmental equity literature. To assess environmental equity, past studies often used indicators such as household income, race/ethnicity, housing ownership, educational attainment, and age. This overlap provides a pathway to link the uneven distribution of environmental amenities (or disamenities) and their benefits to the vulnerability theory. For example, the difference in vulnerability across socioeconomic statuses would be greater when higher levels of exposure (e.g., less urban tree cover) is coupled with higher levels of sensitivity or lower levels of adaptive capacity (e.g., lack of economic resources to cope with the exposure, high sensitivity due to age or pre-existing medical condition, or linguistic isolation of recent immigrants). Thus, given that urban trees can be an effective adaptation strategy that reduces the adverse impacts of climate change, the inequitable distribution of urban tree cover may translate into populations with higher sensitivity or lower adaptive capacity having a higher risk of exposure, widening the vulnerability gap.

CHAPTER 3. METHODS AND DATA

This section provides details on the sources of data, methods for data processing, variable selection, and model specifications. Since the focus of this study is on the longitudinal relationship between urban tree canopy and socioeconomics, the temporal frame of the study is of the greatest importance. The choice of the year in which to conduct analyses was determined by the availability of the two major datasets of this study; urban tree canopy data and socioeconomic data. There were difficulties arising from (a) the fact that changes in tree canopy generally takes long time to be large enough for statistical significance and thus requires a long timeframe, (b) the high-resolution remote sensing data for urban tree canopy is very limited, especially for the early 2000s and (c) the modifications in the census boundary limits the longitudinal comparison of socioeconomic data beyond certain time points. Therefore, the research timeframe was determined under two criteria: (1) the time span for the analysis should be as long as possible, and (2) there should be pairs of reliable datasets for urban tree canopy and socioeconomic variables. The first criterion was given special attention to ensure that the temporal frame spans long enough to capture the bust-and-recovery patterns of the recent economic downturn. The details of the methods and data are delineated below.

3.1 Socioeconomic and Demographic Data

This study uses census block groups within the boundary of the City of Atlanta as the spatial unit of analysis. All sociodemographic and housing-related variables were acquired from census data. After reviewing all possible combinations of census data and remote sensing data, I determined that the period of 2000 to 2013 is the longest time span for which both remote sensing data for urban tree canopy and census data are available. This 13-year period is long enough to ensure that changes in urban tree canopy, as well as the impact of bust-and-recovery pattern, are reflected. For cross-sectional analyses, the Decennial Census 2000 and American Community Survey (ACS) 2013 were downloaded from the Census Bureau website (https://factfinder.census.gov/).

Unlike the cross-sectional analyses, any longitudinal analyses using census data inevitably encounter a challenge due to regular modifications in census boundary. In 2010, there was a boundary modification, and a direct comparison across before and after 2010 is difficult in block group level. A few methods to resolve this issue and compare census data longitudinally has been used, such as area-based weightings or population-based weightings. However, many of the variables of interest are in median values which have limitations for accurate crossover using above methods. For accuracy of some of this study's key variables (e.g., median building age), the Decennial Census 2000 and ACS 2009 were used for longitudinal analysis.

3.2 Urban Tree Cover Data

Similar to the socioeconomic and demographic data, the temporal frame of this analysis is determined by the availability of remote sensing data sources. In order to acquire remote sensing data for the urban tree coverage that spans sufficiently long time periods, this study uses two different sources of remote sensing imageries: (1) National Land Cover

Database (NLCD) and National Agricultural Imagery Program (NAIP). The NLCD is a pre-processed nation-wide remote sensing dataset with 30-meter spatial resolution prepared for the year 2001, 2006, and 2011 by Multi-Resolution Land Characteristics (MRLC) Consortium. It uses various remote sensing imageries to provide land cover, land cover change, tree canopy cover, and impervious surface data (Homer et al. 2007; Homer et al. 2015). The urban tree cover data for 2001 and 2011 was derived from NLCD.

The methods used to calculate tree canopy cover in NLCD vary by years in terms of the target definition of trees (Fry et al. 2011). In NLCD 2001, the definition of trees was those taller than 5 meters whereas NLCD 2011 did not have height restrictions. Researchers found that NLCD 2001 tend to underestimate tree cover (Nowak and Greenfield, 2010), which may limit the comparability of the dataset in different years. If NLCD 2001 and NLCD 2011 are to be compared without significant bias, the underestimation should be evenly distributed across all study areas. If it is possible to assume an even distribution of underestimation, the coefficients and statistical significances of variables in regression models (except for intercept) would not be considerably biased and thus relatively comparable. For example, if the underestimation of NLCD 2001 is significantly concentrated in dense urban areas where potential planting areas and available soil volume, light, and space for growth is limited, but does not occur as much in heavy forests, a scatterplot between NLCD 2001 and 2011 would show a non-linear pattern which would look similar to a hockey stick. To see if it is possible to make this assumption, scatterplots between NLCD 2001 and 2011 were generated (Figure 3). Based on visual observation, the scatterplots appear to be evenly scattered around a linear line. Thus, I concluded that NLCD 2001 and 2011 are reasonably comparable.

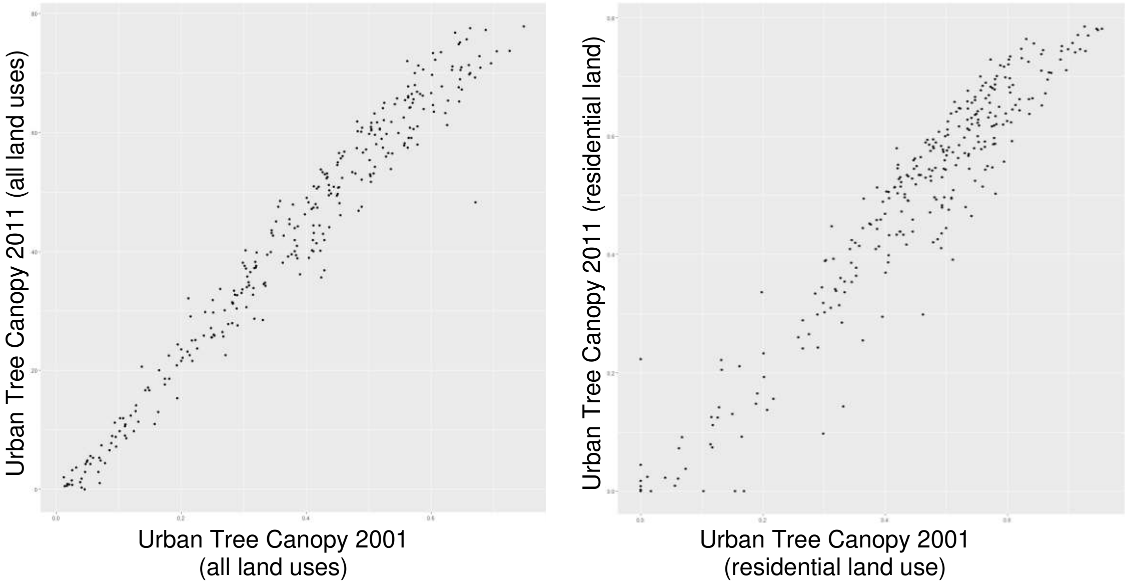

Figure 3. Scatterplot between NLCD 2001 and 2011 in the Entire City Area (left) and in the Residential Area (right)

The urban tree cover data for 2013 was derived from NAIP imageries. The NAIP is a program administered by the United States Department of Agriculture (USDA)'s Farm Service Agency (USDA website, accessed February 10, 2017). It provides four-band aerial imagery with the spatial resolution of 1 meter, taken during 'leaf-on' season. Beginning in 2009, NAIP imageries for all states adhere to the absolute accuracy specification standard which requires that "all well-defined points tested shall fall within 6 meters of true ground at a 95% confidence level (USGS, accessed on February 17, 2017)". The imageries were downloaded from a data portal of USGS called Earth Explorer and each NAIP imageries covering parts of Atlanta area were mosaicked. The mosaicked imagery was categorized into 80 classes using iso-cluster unsupervised image classification in ArcGIS 10.1. This imagery with 80-classes was reclassified into four categories of tree canopy, non-tree vegetation, impervious surface, and shadow. Finally, obvious misclassifications were removed by manually drawing polygons. The overall accuracy for the image was 85.6%.

This study examines the urban trees located in residential land uses within block group boundary. This approach assumes that the benefits of urban trees on residential land uses apply to all residents within the block group but not to residents in other block groups. Although this assumption may not be accurately reflecting the way urban trees influence urban residents if any two or more block groups are located next to each other and thereby are in proximity close enough to share the benefits of trees planted in nearby block groups, this method was applied for two reasons: (1) a past study using hedonic property price model reported that urban trees within 250 meter from a residential parcel is positively associated with property price but the effect becomes statistically insignificant beyond 250 meters (Sander, Polasky, and Haight, 2010) and (2) this approach has been applied in many past studies (Landry and Chakraborty 2009; Troy et al. 2007; Donovan and Butry 2010; Jenerette et al. 2011). To identify the locations of residential land uses, land cover data for the corresponding years provided by Atlanta Regional Commission were used to filter out areas of non-residential uses.

Figure 4. shows final selections of the temporal frame for cross-sectional models and a longitudinal model with major data sources for each model. Note that NLCD and NAIP are different in many aspects, particularly in their spatial resolution. Due to these differences, NLCD and NAIP are not suitable to be compared to one another. Thus, the regression models in this study were specified such that NLCD and NAIP are not used in the same model. For the first cross-sectional regression model, socioeconomic data from the Decennial Census 2000 is matched with urban tree canopy data from NLCD 2001. The longitudinal regression model uses the Decennial Census 2000 and ACS 2009 for socioeconomic variables, and NLCD 2001 and NLCD 2011 for urban tree canopy data.

Finally, the second cross-sectional regression model uses ACS 2013 and NAIP 2013. These pairings of datasets provide the maximum of 13-year temporal frame as a whole and the minimum of four-year time gaps between each model in terms of census data, allowing effective comparisons amongst different time points.

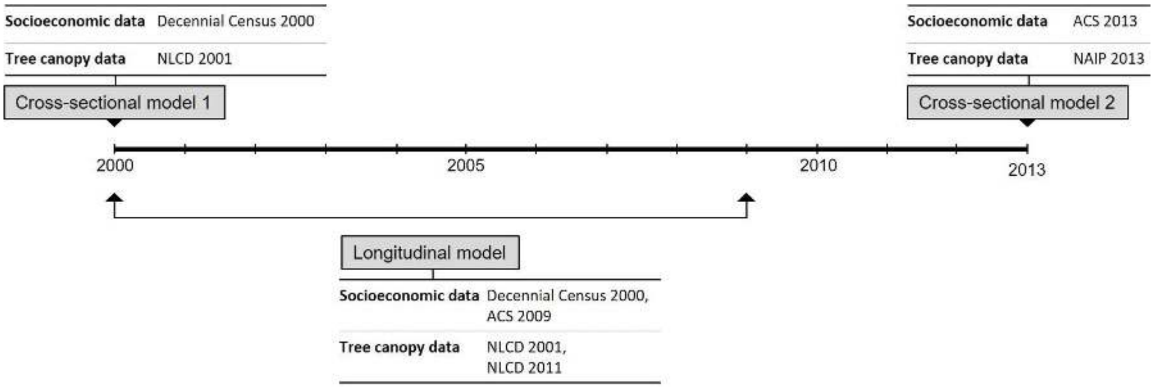

Figure 4. Timeframe and Data Source for Cross-Sectional and Longitudinal Models

3.3 Variables

Explanatory variables were selected from two different fields of studies. As mentioned above, variables frequently used in environmental equity and vulnerability theory tend to overlap. These overlapping variables, particularly those with significant effects reported in past studies, were given priority in variables selection. (Heynen and Lindsey, 2003; Cutter, Boruff, and Shirley, 2003; Grove et al, 2006a; Troy et al., 2007; Landry and Chakraborty, 2009; Lowry, Baker, and Ramsey, 2012; Pham et al., 2012; Jesdale, Morello-Frosch, and Cushing, 2013; Danford et al., 2014; Krafft and Fryd 2016). Importantly, many of variables initially tested for analysis were excluded due to the risk of multicollinearity. For example, median housing value and percent population with bachelor’s degree or higher had a significantly high correlation with percent African-American (Pearson’s correlation above 0.85) in cross-sectional models.

In addition to the variables commonly used in previous studies, this study includes an interaction effect between race and poverty. In locational attainment model, the percentage of White (or African-American) and the poverty rate has been used to explain the relationship between racial groups and their neighborhood outcomes (Sampson and Sharkey 2008). Given the recent trend of White-infill and suburbanization of non-White population, particularly middle- or upper-class non-Whites, which are described in the latter sections in detail, I hypothesized that the effect of race on residential location choice would vary to a significant degree depending on the level of economic resources. There has been stratification within same racial groups, and that of African-American has been particularly addressed in many public medias (Gates, 2016). which, in turn, may diversify the decision on residential location choice within African-American (Charles, 2003). The interaction terms were tested for all models in all possible combinations of race categories and poverty measure. In the regression results, however, only those that were statistically significant were considered for further interpretations. Table 2 presents descriptive statistics of the variables used in regression models.

Table 2. Descriptive statistics of variables used in regressions.

	2000		2009		2013		Data source
	Min	Mean	Min	Mean	Min	Mean	
	Max	s.d.	Max	s.d.	Max	s.d.	
Land use diversity	0.000	0.506	-	-	0.000	0.488	Atlanta Regional Commission
	1.000	0.279			0.998	0.264	
Intersection density	6.697	99.753	-	-	50.09	483.62	Census Tiger 2000, 2009, 2013
	323.27	60.716			2062.19	331.10	
Population density (acre)	0.244	5.310	-	-	0.233	5.433	Decennial 2000 ACS2009, 2013
	44.876	4.373			64.157	5.273	
Percent age 0 to 4	0.000	0.062	0.000	0.068	0.000	0.066	Decennial 2000 ACS2009, 2013
	0.207	0.033	0.395	0.056	0.230	0.049	
Percent age 65 and over	0.000	0.107	0.000	0.091	0.000	0.112	
	0.480	0.071	0.426	0.075	0.549	0.086	
Percent African American	0.000	0.635	0.000	0.587	0.000	0.546	
	0.994	0.392	1.000	0.394	1.000	0.390	
Percent Asian	0.000	0.016	0.000	0.020	0.000	0.027	
	0.407	0.039	0.235	0.039	0.333	0.051	
Percent Hispanic or Latino	0.000	0.037	0.000	0.043	0.000	0.043	
	0.793	0.074	0.841	0.092	0.626	0.071	
Percent bachelor's degree or higher[a]	0.000	0.301	0.000	0.376	0.000	0.440	
	0.954	0.281	0.956	0.289	0.947	0.289	
Percent home ownership	0.000	0.452	0.000	0.504	0.000	0.480	
	0.981	0.260	1.000	0.272	1.000	0.265	
Percent in poverty	0.000	0.246	0.000	0.250	0.000	0.252	
	0.771	0.183	1.000	0.214	1.000	0.193	
Median building age	3.00	41.00	-	-	9.00	47.00	
	61.00	11.825			74.00	18.90	

a. 'percent bachelor's degree or higher' was only included in the longitudinal model. In the cross-sectional model, this variable suffered from multicollinearity with variance inflation factors over 10.

3.4 Statistical Analysis

Past studies on environmental equity have widely utilized spatial regression models to address the issue of spatial autocorrelation. Spatial autocorrelation refers to the case where values of samples in the dataset are not randomized because of geographic proximity. If not treated with adjusting measures, the presence of spatial autocorrelation would bias the estimate from OLS models. The spatial regression model is one way to address the issue of spatial autocorrelation through an inclusion of the effects of spatial dependence into the standard linear regression model (Anselin and Bera 1998; Landry and Chakraborty 2009). Following the method used by Landry and Chakraborty (2009), the statistical analysis consists of multiple steps. First, ordinary least squares (OLS) regression models were developed using the set of variables described above. Second, regression residuals generated from the OLS models were tested for autocorrelation using global Moran's I statistics. Lastly, choice of models between OLS model and spatial regression model of made based on the spatial dependence. The SAR model determines the spatial relationship among observations in data using spatial weight matrix, which contains information on whether an observation A is neighboring with observation B. This study used row-standardized queen contiguity method to build the spatial weight matrix.

The response variables used in the following models, which are the percentage of tree canopy cover in a given single year or the change in tree canopy cover between two years, has significantly high global Moran's I value, suggesting the existence of spatial autocorrelation. To solve the problem of the autocorrelation of the error term, simultaneous autoregressive (SAR) models were used. The model selection between spatial lag and spatial error model was done based on Lagrange Multiplier statistics (Anselin 2013).

The structures of regression equations differed depending on whether it is cross-sectional or longitudinal models. For cross-sectional models, the percentages of urban tree cover (TREE) were matched with built environment (BUILT), housing characteristics (HOUSE), and socioeconomic (SOCIO) variables from the corresponding years (equation 1).

Cross-sectional equation:

$$\text{TREE} = c + [\alpha][\text{BUILT}] + [\beta][\text{HOUSE}] + [\theta][\text{SOCIO}] + \rho W y + \varepsilon \quad (1)$$

where ρ is the spatial autoregression coefficient, W is the spatial weight matrix, y is the spatially lagged dependent variable, and ε is the error term.

For longitudinal model, a few modifications were made due to (1) incomplete comparability between NLCD 2001 and NLCD 2011 data and (2) the risk of multicollinearity in cross-sectional models are much less significant in the longitudinal model. For the socioeconomic variables, both the base year value in 2000 and the changed value between 2000 and 2009 are included. For example, the proportion of Asian population in 2000 and the change in the proportion of Asian are both included. Note that although NLCD 2011 is modeled as the dependent variable, an inclusion of NLCD 2001 allows coefficients of independent variables in equation (2) to be interpreted as the relationship between the change in socioeconomic status and the change in urban tree cover (Galster and Cutsinger, 2007). The final equation estimated for the longitudinal model was:

Longitudinal equation:

$$\begin{aligned} TREE^{11} = c + [\alpha][TREE^{00}] + [\beta_1][BUILT^{00}] + [\beta_2][\Delta BUILT^{11-00}] \\ + [\Phi_1][SOCIO^{00}] + [\Phi_2][\Delta SOCIO^{09-00}] + [\gamma][\Delta RES^{09-00}] + \lambda W \upsilon + \varepsilon \end{aligned} \tag{2}$$

where λ is the spatial autoregression coefficient, W is the spatial weight matrix, υ is the spatially dependent error term, and ε is the independent identically distributed error term.

CHAPTER 4. RESULTS

4.1 Geography of Urban Tree Canopy in Atlanta

According to NLCD 2001 and 2011, urban tree cover in the city boundary area was estimated to be 44.95% and 49.20%, respectively. Considering the reports from the past studies that tree canopy in Atlanta is in decline (Nowak and Greenfield, 2012), it may be counterintuitive that the percentage of tree canopy in 2011 is greater than that in 2001. As mentioned earlier in this study, the definition of trees used in NLCD 2001 was more restrictive than that used in NLCD 2011, which resulted in the underestimation of urban tree canopy in NLCD 2001 (Greenfield, Nowak, and Walton 2009). This underestimation may be the reason for what appears to be an increase in tree canopy in 2011. In 2013, the urban tree canopy estimates using NAIP data showed that 51.56% of the area in the city boundary was covered by urban tree canopy. This estimate using NAIP 2013 is virtually identical to that of Nowak and Greenfield (2012) who reported 51.6% tree cover in Atlanta, and slightly higher than the figure reported in urban tree canopy assessment conducted by the City of Atlanta (2014) and the Center for Geographic Information System who reported 47.9% tree cover in Atlanta in 2008. Note that the results of image classification in previous studies vary to some degree because of the innate subjectivity involved in the image classification procedure. Nonetheless, the urban tree canopy estimate for 2013 appears to be acceptably accurate, based on the comparison with the past findings and the accuracy assessment. Figure 5 to figure 7 show the distribution of urban tree canopy in NLCD 2001, NLCD 2011, and NAIP 2013 in 500 feet by 500 feet grid (roughly 6 acres). The underestimation of NLCD 2001 is also visible in figure 5, showing relatively lighter color compared to NLCD 2011 and NAIP 2013.

The visual observations of these images clearly show a concentration of non-tree land covers at the central part of Atlanta where downtown and midtown are located. The concentration of non-tree land cover appears to spread following the road infrastructure. To the north and west of the downtown and midtown, clusters of dense, non-tree land covers are visible, which are rail yard and the sub-centers in Buckhead District such as Lindberg. Throughout all images, the overall patterns of urban tree canopy tend to remain stable with a few exceptions where large developments occurred. This consistency is also observed in correlation analysis between NLCD 2001 and NLCD 2011 using the 500 ft. by 500 ft. grid cells as observation units (correlation coefficient 0.916, $p<0.001$, $n = 15,683$).

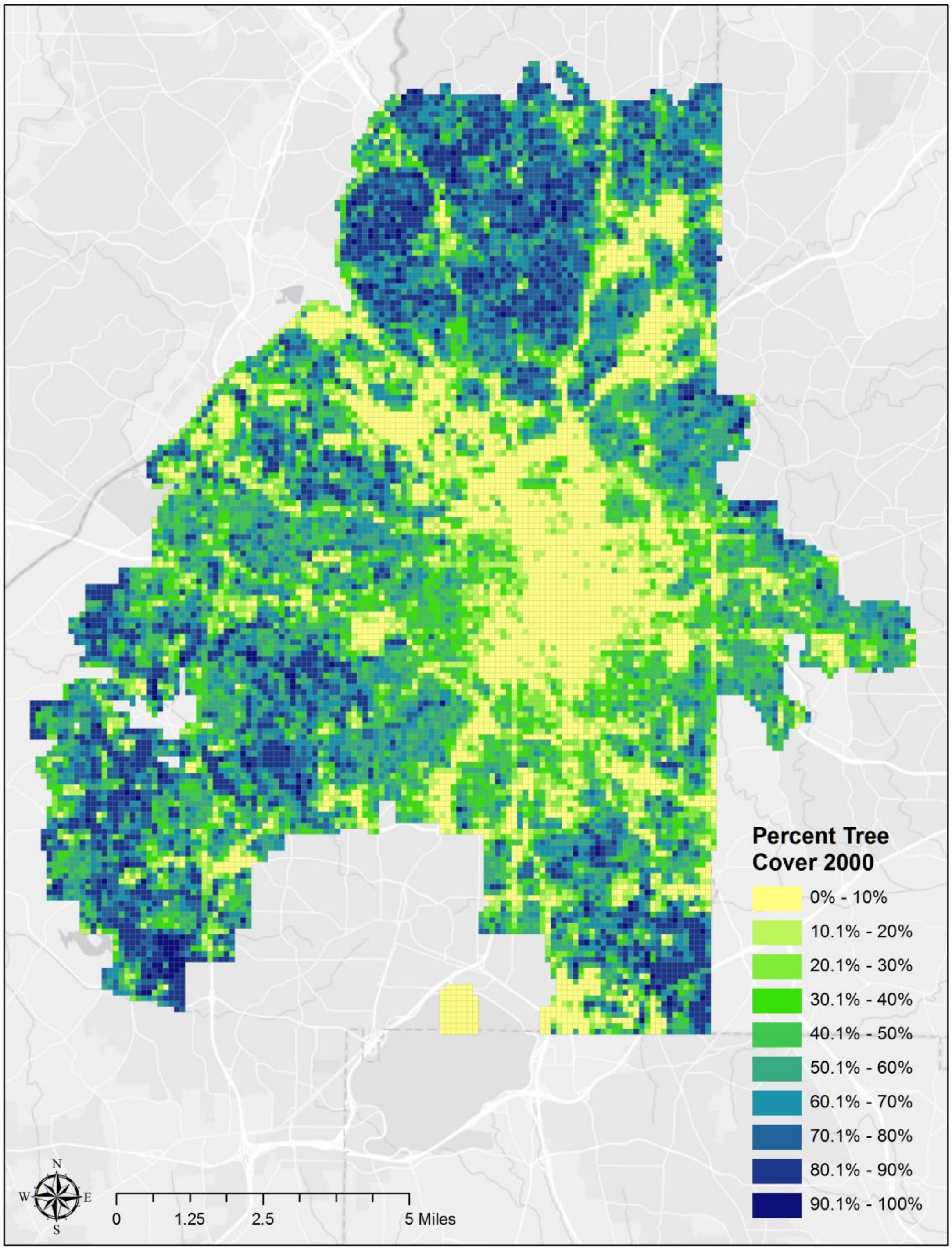

Figure 5. Urban Tree Canopy in 2000 (by 500ft. by 500ft. Grid)

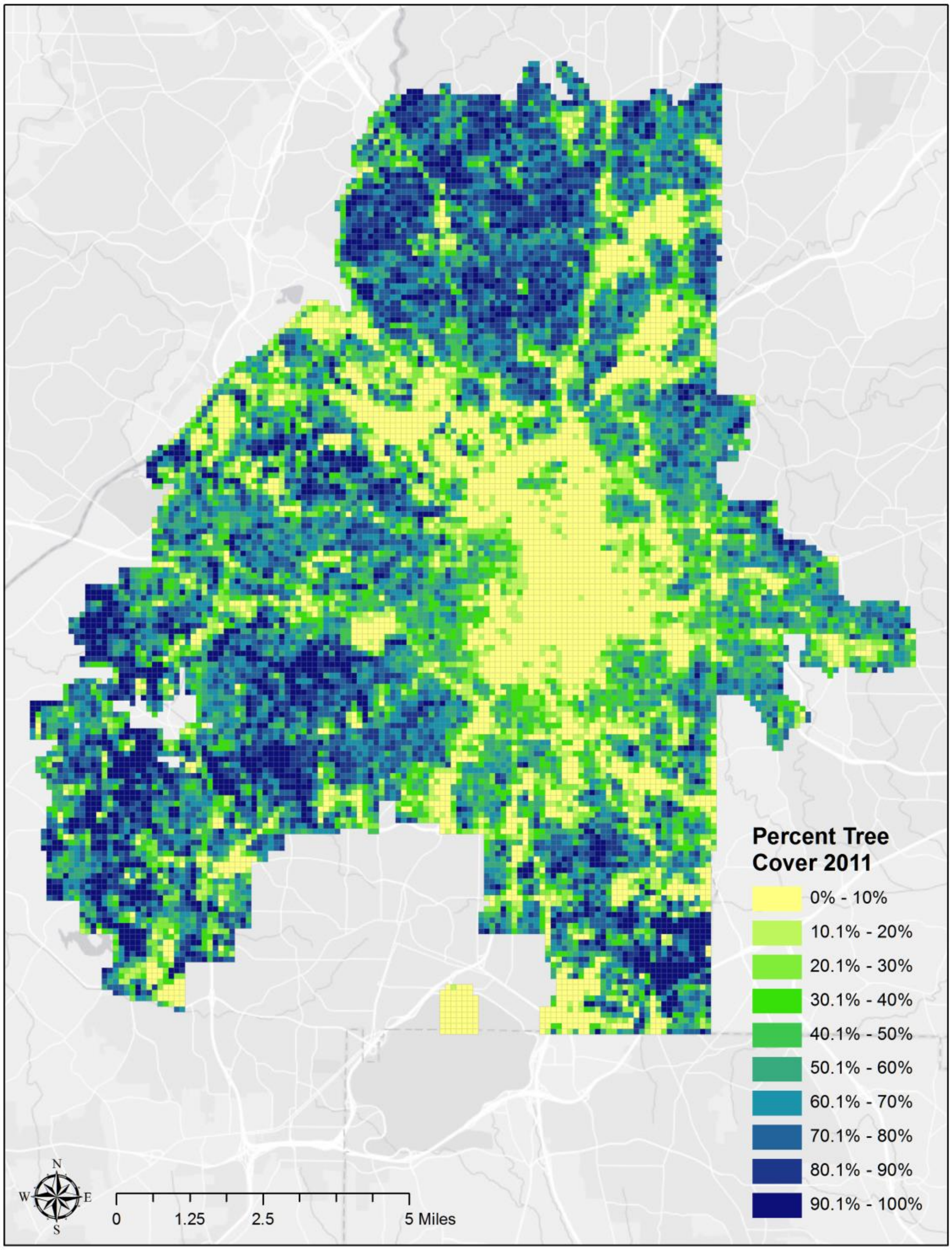

Figure 6. Urban Tree Canopy in 2011 (by 500ft. by 500ft. Grid)

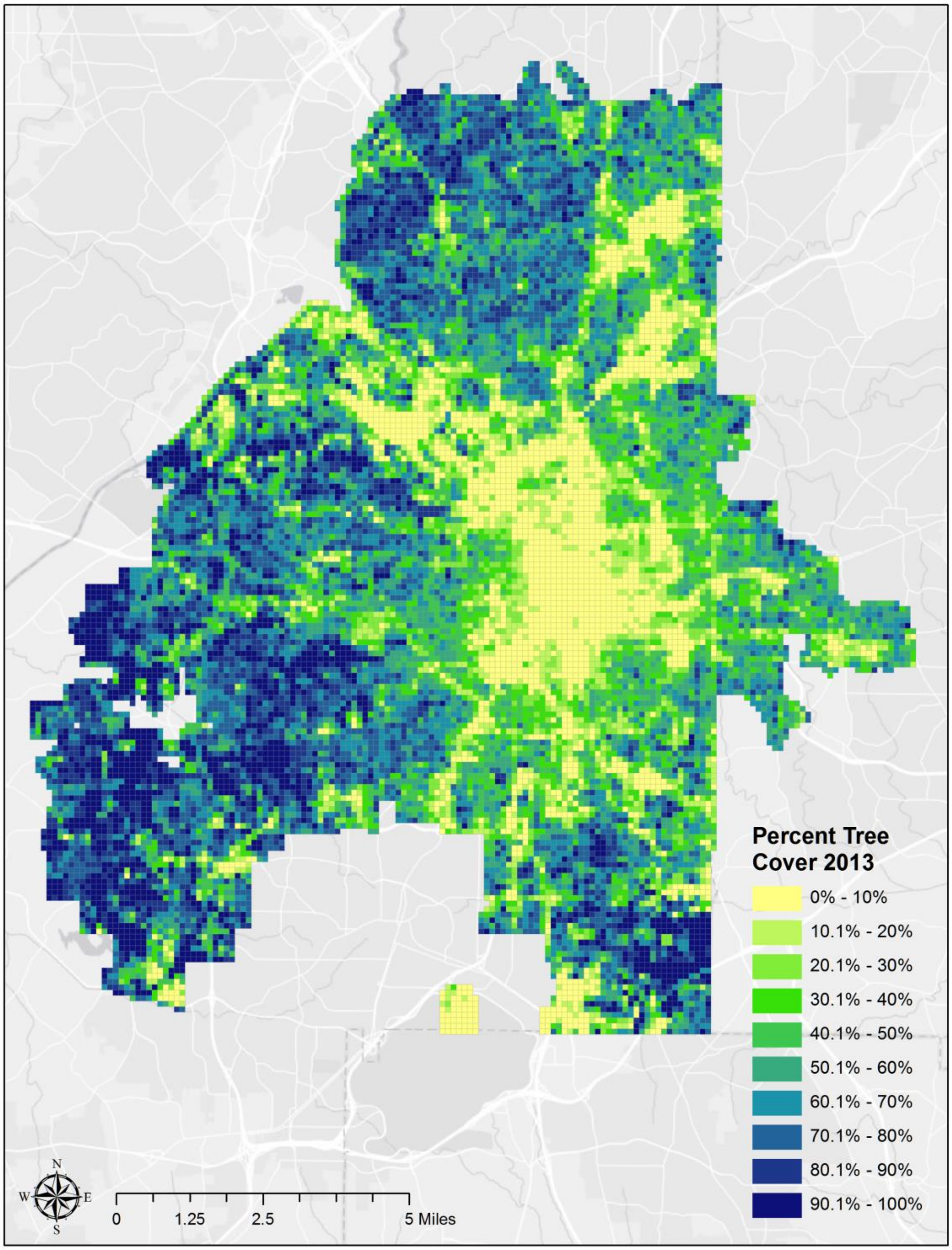

Figure 7. Urban Tree Canopy in 2013 (by 500ft. by 500ft. Grid)

The difference between these images offer a general understanding on where urban tree canopy has been decreasing or increasing. Figure 8 show the differences between NLCD 2011 and NLCD 2001. Note that because of inconsistencies in the definition of trees, figure 8 can be best interpreted by examining the relative patterns of increase or decrease in different parts of the city rather than examining actual breakpoints. Figure 8 indicates that the southern half of the city had seen increases in urban tree canopy whereas the northern half of the city had experienced a mix of increases and decreases. Since the NLCD 2001 is underestimating the urban tree canopy, an increase in figure 8 may be overestimated and a decrease may be underestimated.

Narrowing down to residential areas, the estimate of urban tree canopy by NLCD is 54.76% and 59.81% in 2001 and 2011, respectively. The same underestimation seen in the urban tree canopy for the entire city area was observed here as well. The urban tree canopy in 2013 by NAIP is 59.31%. These numbers indicate that the residential areas had a greater urban tree canopy compared to the entire city area, which aligns with the finding from other urban tree canopy assessments (see, for example, the City of Atlanta 2014). Table 3 presents the summary of urban tree canopy in Atlanta.

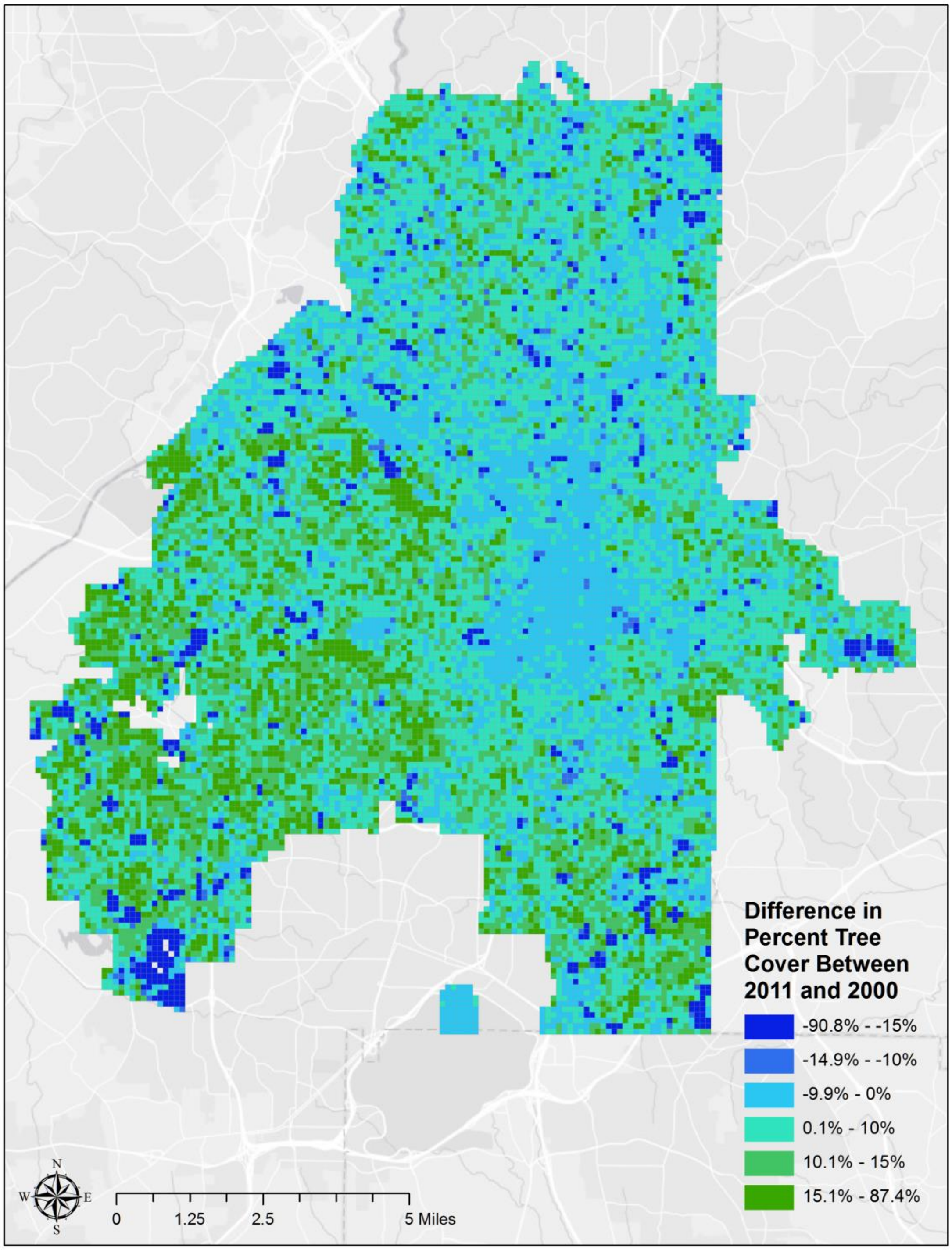

Figure 8. Difference in Urban Tree Canopy between 2011 and 2001 (by 500ft. by 500ft. Grid)

Table 3. Urban Tree Cover in Atlanta

	Urban Tree Cover		
	2001 (NLCD)	2011 (NLCD)	2013 (NAIP)
Entire City Area	44.95%	49.20%	51.56%
Residential Land Uses	54.76%	59.81%	59.31%

The percentage of residential land covered by urban tree canopy in census block group scale greatly varied in different parts of the city (figure 9 and figure 10). In both 2001 and 2011, the northern residential areas are heavily forested whereas the inner-city area around downtown and midtown had the lowest urban tree canopy. Figure 11 shows the hot spots of the changes in residential tree canopy in residential lands where block groups in blue represent clusters of low values (decreases in urban tree canopy) and ones in red represent clusters of high values (increases in urban tree canopy) between 2000 and 2011. It is clear that the residential areas in downtown and midtown have been *losing* tree canopy and the loss of trees stretches along I-85. Conversely, some of the block groups that has been traditionally African-American neighborhoods saw an *increase* in the tree canopy. The impact of this change to the environmental equity in Atlanta will be further dismantled in the regression models in conjunction with socioeconomic variables. Although indefinite, the pattern in which tree canopy has changed over time may have been affected to some degree by the impact of the recent economic downturn occurred in late 2006 and 2007. A study by Raymond, Wang, and Immergluck (2016) identified that the southern half of the city had seen a steep drop in housing price with little recovery after the crisis. The northern part of the city, on the other hand, had more than recovered from the bust in general. This disparity might have resulted in differential levels of constructions in different parts of the city, leading to an uneven increase/decrease in tree canopy.

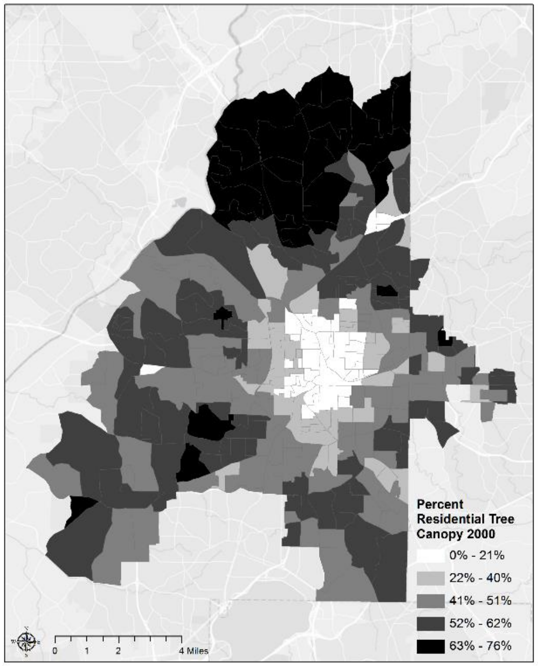

Figure 9. Percent Residential Tree Canopy in 2001 by Census Block Group

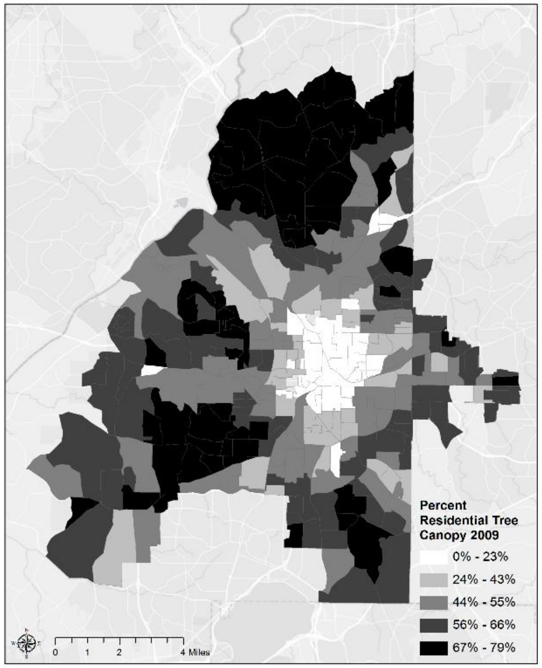

Figure 10. Percent Residential Tree Canopy in 2011 by Census Block Group

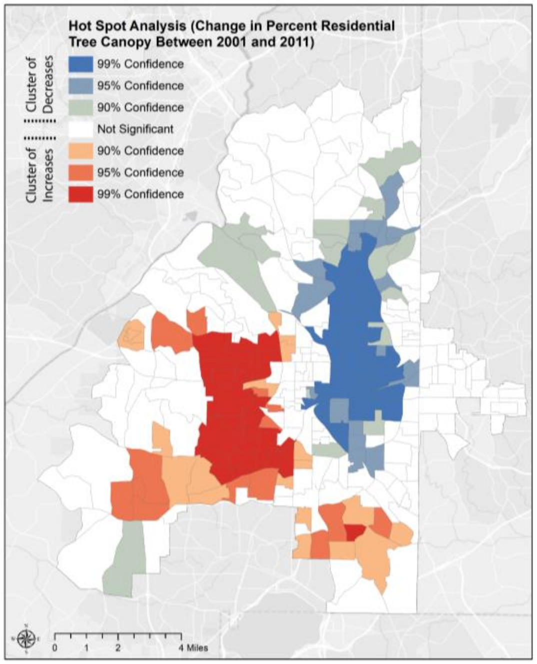

Figure 11. Change in Percent Residential Tree Canopy between 2001 and 2011

4.2 Geography of Socioeconomic Status in Atlanta

In the environmental equity discourse, the residents' socioeconomic status and the neighborhoods' level of environmental desirability function as important factors determining where people choose to live (Eckerd 2011). Higher socioeconomic status is often translated into resources with which people can prevent environmental degradations or foster environmental improvements of their neighborhoods, or attain desirable neighborhoods. The manifestation of these neighborhood choices and the results of the actions for improvements are essentially what determines an equitable/ inequitable distribution of urban tree canopy across the socioeconomic spectrum. This makes an examination of the changes in the socioeconomic/demographic geography of Atlanta worthwhile.

Atlanta has been a center of African-American economy, culture, and political power (Brookings Institute 2000; Strait and Gong 2015). In spite of the city's reputation as "black mecca", the city has seen a constant decrease in the proportion of African-American while that of White is steadily increasing. Table 4 shows the population change by racial groups in Atlanta between 2000 and 2013 in the order of largest to smallest racial groups. In 2000, the city had 416,474 populations, of which 61.4% was African-American, 33.2% was White, and 1.9% was Asian. Between 2000 and 2013, the proportion of African-American has fallen to 53.5% (relative change of -9.4%) and that of White has increased to 39.3% (relative change of +23.0%). The increase in the White population of the city between 2000 and 2013 (+31,824) was larger than the increase in the total population of the city (+16,115), indicating that the city is rapidly becoming whiter. Nonetheless, the sum of White and African-American has constantly exceeded 90% regardless of years, making White and African-American the two dominant racial groups in the city. The relative increase in Asian population, the third largest racial group in the city, is also notable. Between 2000 and 2013, the Asian population had increased by 94.8%. Despite this large increase, however, the absolute number of Asian population was only 3.6% of the total population in 2013. The increase in the number of Hispanic or Latino, although it is not a racial group, is also notable. Between 2000 and 2013, the number of Hispanic or Latino had increased from 18,720 to 23,089 (relative change of 23.3%).

Table 4. The change in population by race between 2000 and 2013

year	African American	White	Asian	Other races	Total	Hispanic or Latino
2000	255,689 (61.4%)	138,352 (33.2%)	8,046 (1.9%)	14,387 (3.5%)	416,474	18,720 (4.5%)
2013	231,628 (53.5%)	170,176 (39.3%)	15,674 (3.6%)	15,111 (3.5%)	432,589	23,089 (5.3%)
Difference 2000-2013	-24,061	+31,824	+7,628	+724	+16,115	+4,369
Relative Change	-9.4%	23.0%	94.8%	5.0%	3.9%	23.3%

In the parenthesis is the proportion of the racial group.
The figures in the total column do not include Hispanic or Latino.

As presented in table 5, the median income of the city increased from $56,824 to $56,972 (relative change of 0.26%, inflation adjusted to 2013 U.S. Dollar) between 2000 and 2013. In the same period, the national median income has increased from $58,709 to $53,046 (relative change of -9.64%). Although the change in median household income of Atlanta was marginal, the comparison with national statistic indicates that it is economically outperforming than the nation as a whole. This trend can be observed in other socioeconomic indicators such as educational attainment and home ownership. In the same period, the proportion of people aged 25 and above holding bachelor's degree or higher has increased by 13.9%, which far exceeds that of the national average of 4.6%. The home-ownership also has risen by 2.8% during the same period. However, these improvements are not equally distributed across the socioeconomic spectrum: the city had one of the highest Gini index value, which depicts the level of inequality, amongst all U.S. cities with at least 250,000 populations in 2014 (Bloomberg, 2014). The poverty rate also had increased by 0.6% in the same period.

Table 5. The change in socioeconomic indicators of Atlanta between 2000 and 2013

year	Median Household Income*	Bachelor degree or Higher	Home-Ownership	Poverty
2000	$56,824	30.1%	45.2%	24.6%
2013	$56,972	44.0%	48.0%	25.2%
Difference 2000-2013	+$148	+13.9%	+2.8%	+0.6%
Relative Change	0.26%	46.1%	6.19%	0.41%

* Median household income reported in this table is the average of median household income of 305 block groups within the boundary of the city of Atlanta

* Figures for 2000 and 2010 is inflation-adjusted to 2013 dollar

Narrowing down to sub-city level, this inequality is closely related to racial issues, which has a strong geographic dimension that can be visually observed in a form of clear line separating the city into two by race (Figure 12 and 13). The northern Atlanta has predominantly White residents, and African-American residents are concentrated in the southern half of the city, cutting the city into two. This division between north and south of the city can roughly be translated into a division of wealth and prosperity (Brookings Institute 2000). Although the city and the region experienced a rapid growth in population, jobs, and wealth, the majority of them occurred in the northern part of the city and suburbs beyond the city boundary (Brookings Institute, 2000). Similarly, the African-American middle-class residents also moved out of the city into suburbs, often to the south of the city (Strait and Gong, 2015).

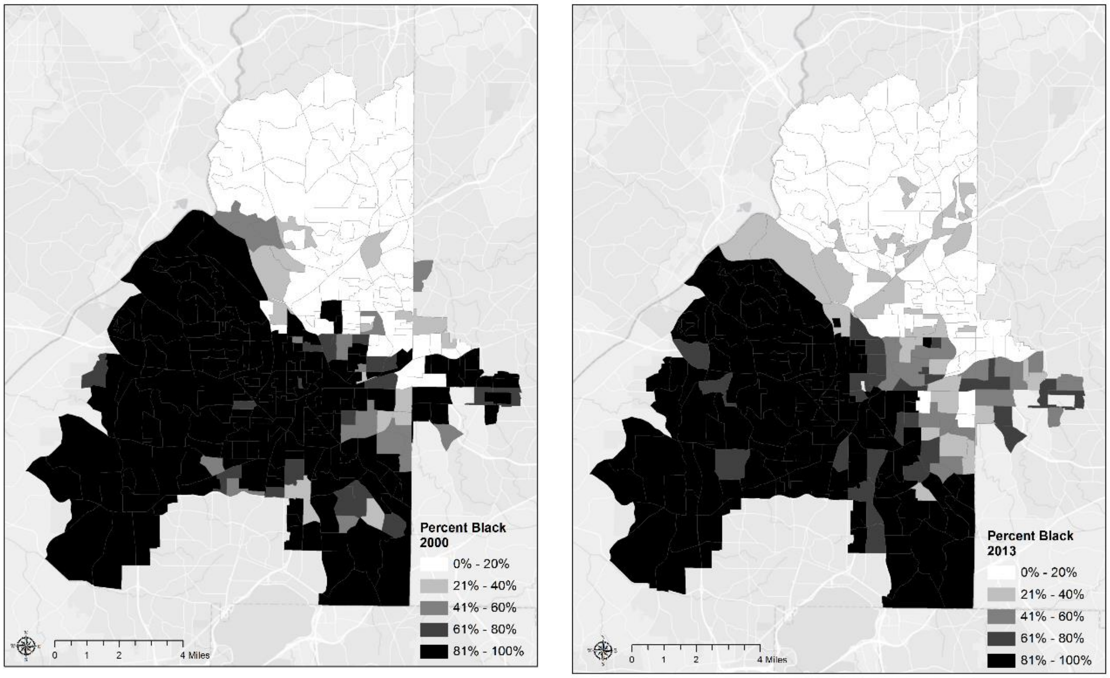

Figure 12. Percent African-American - Left: 2000, Right: 2013

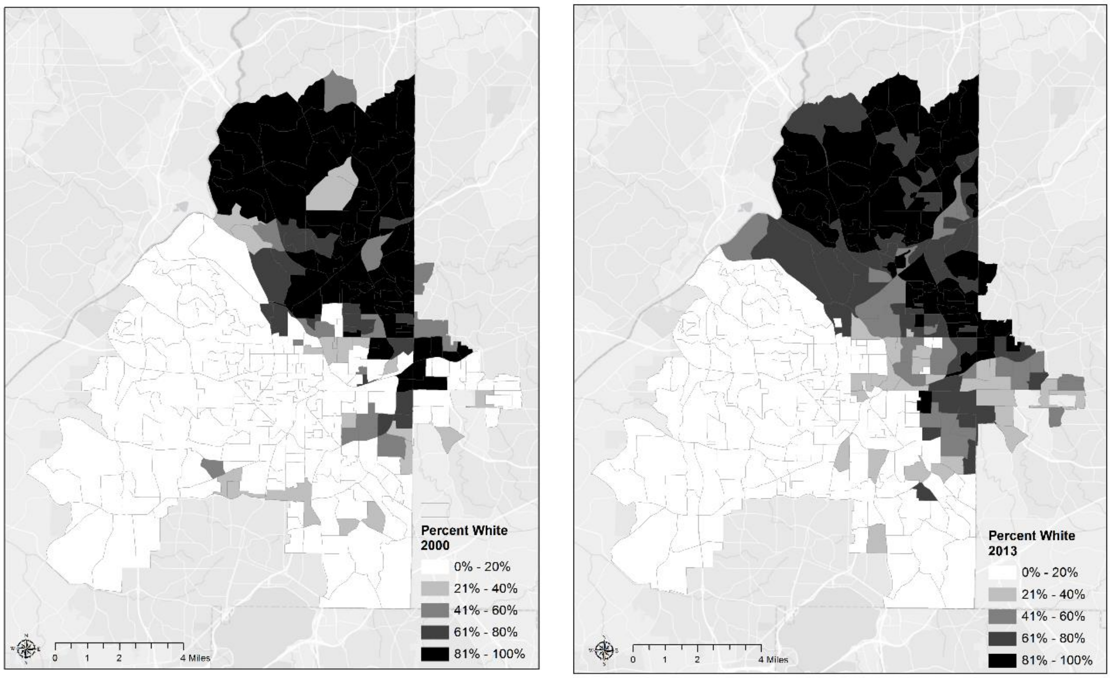

Figure 13. Percent White - Left: 2000, Right: 2013

Between 2000 and 2013, Atlanta has seen many redistributive changes. One of the most distinctive trends that have been frequently reported in past studies and public media is an increasing White population in the inner-city areas (Aka, 2010; Strait and Gong 2015). This racial transformation has been so dramatic that "Atlanta has outpaced all other U.S. cities in that category" (Jennings, 2016, 3). Figure 14 and 15[1] show the hot spot analysis on the change in the percentage of African-American (left) and the percentage of White (right). The block groups in blue represent clusters of low values (decreases in the percent African-American or White) and ones in red represent clusters of high values (increases in the percent African-American or White). It is clear that the downtown area and its

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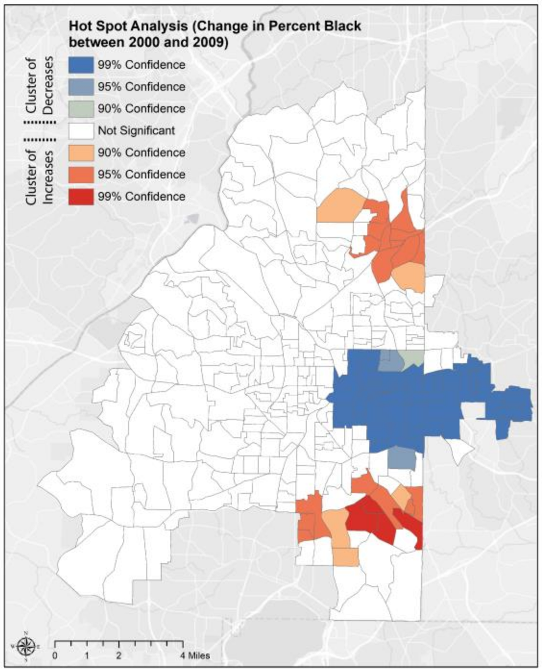
[1] Because the census boundary change in 2010 makes a direct comparison before and after 2010 in census tract level cumbersome, figures that require tract-level operations (e.g., subtraction or addition) are created using data from 2000 and 2009.

neighboring block groups to the west has seen a significant decrease in the share of African-Americans while gained a higher proportion of White residents between 2000 and 2009. The block groups shown in red or blue (99% confidence) in figure 14 and 15 had seen, on average, 17.6% increase in the percentage of White population and 19.6% decrease in the percentage of African-American population over the course of nine years. At the same time, non-White populations have been rapidly increasing in suburban areas (Strait and Gong, 2015) which resulted in 87% of the African-American population living in suburban neighborhoods in 2010 (Pooley, 2015). In sum, the inner-city area appears to be having a turn-over from predominantly African-American neighborhoods to whiter neighborhoods. Although the discussions on the suburbanization of non-Whites in the literature are often made with the regional geographic perspective beyond the city limit, which makes it difficult to clarify the strength and direction of impact within the city boundary, it is reasonable to conclude that the racial and socioeconomic landscape in Atlanta has been changing at least in modest degree.



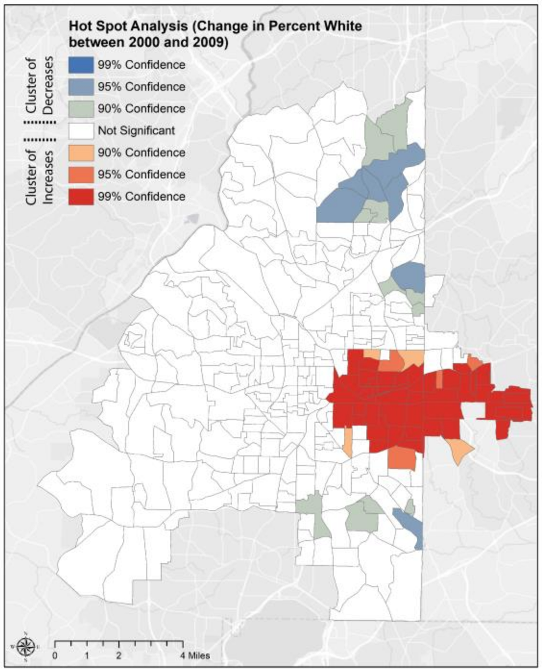


Figure 14. Hot Spot Analysis on the Change in the Percent African-American between 2000 and 2009

Figure 15. Hot Spot Analysis on the Change in the Percent White between 2000 and 2009

Not surprisingly, this so-called 'White-infill' in the traditional city center is associated with Atlanta's gentrification (Keating, 2010; Blau, 2015). Figure 16 and 17 show the poverty rate and median household income for 2000 and 2013. A recent study revealed that the values of housing in proximity to the Beltline, the 22-mile ring of redevelopment project circling around the core of Atlanta, has seen a rapid rise (Immergluck, 2007). This gentrification has been causing racial tension (Keating, 2010; Aka, 2010). Aka (2010) writes, "racial transition is a characteristic of gentrification in Atlanta because many persons moving into predominately black in-town neighborhoods are white. The social and economic differences between blacks and whites create conflict (p. 2-3)." He further writes, "some black residents blame the state of inner-city urban America on the past actions of whites. They see the influx of middle-income whites back into the central city, not as a source of good, but as a ‘take over’ (p. 6).” The changing geography of racial groups and median household income shown in figure 17 depicts these trends: many African-American dominant block groups with the median household income between roughly $34,000 to $60,000 observed in the south of the city center in 2000 (light grey in figure 17) has shifted to the poorest category with income less than $34,000. However, suburban areas experienced a decline in African-American poverty rate, which may be reflecting the tremendous growth of African-American population, particularly middle- to high-income class African-American residents in suburban areas (Lee, 2011). This out-migration of middle to high socioeconomic classes had left a concentration of poverty, particularly in the center of the city (Brookings Institute, 2000). Similarly, a study by Lee (2011) documented that a decrease in the proportion of the Black population between 1980 and 2000 is one of statistically significant predictors of the higher level of poverty among Blacks in 2000 (Lee, 2011). The poverty maps shown in figure 16 indicates that the concentration of poverty in the city center observed in 2000 has been somewhat alleviated in 2013. At the same time, however, the number of block groups with the poverty rate of 20% to 40% has decreased between 2000 and 2009 while those with the poverty rate of 40% to 60% has increased in the same period.

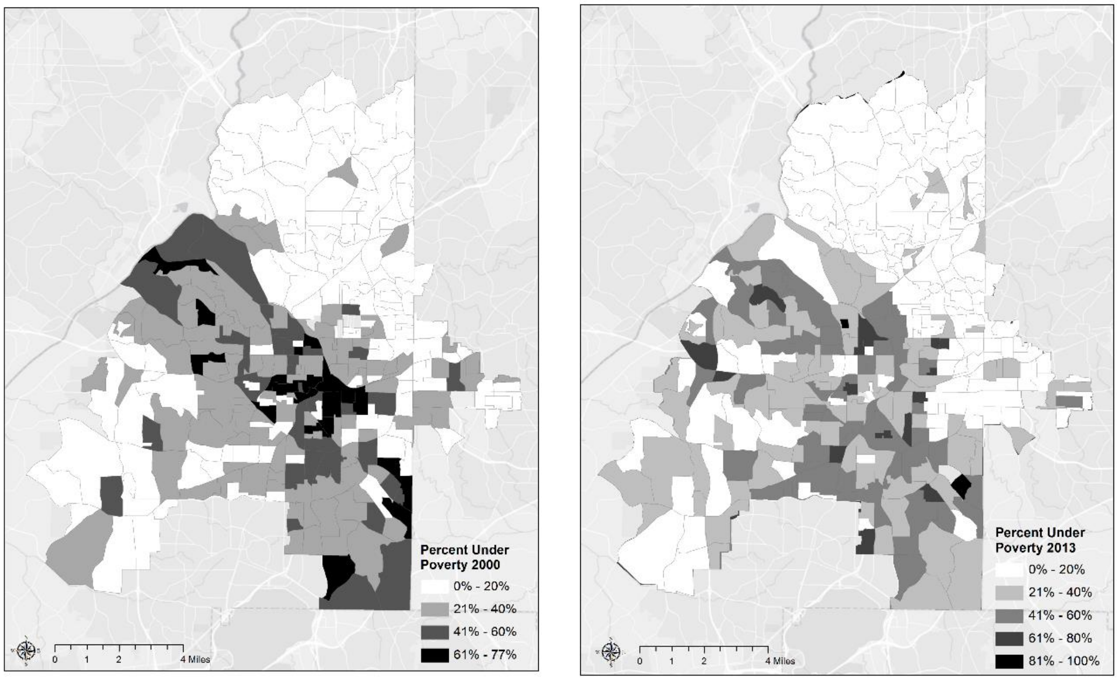


Figure 16. Percent Under Poverty - Top: 2000, Bottom: 2013

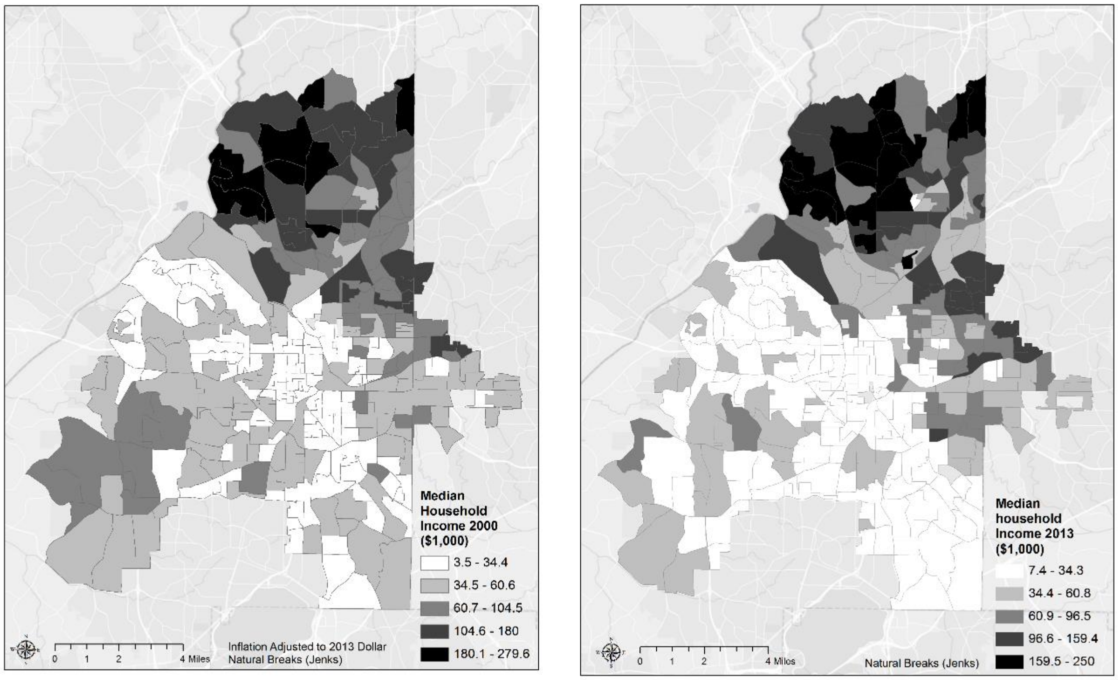


Figure 17. Median Household Income - Top: 2000 (inflation-adj.), Bottom: 2013

Interestingly, a closer examination on median household income by race revealed that the income of African-Americans in the inner-city also has risen between 2000 and 2009 (figure 18 and 19). In 2000, the average of median household income of African-American in 18 block groups in the downtown area was $19,782 whereas that of all other block groups in the city was $30,151. Between 2000 and 2009, the average of median household income of African-American in the same 18 block groups in the downtown area increased by $11,517 while that of the rest of the city increased by $2,006. This difference indicates that the increase in the median household income in the city center may be attributable to both Whites and African-Americans. The interpretation of the implication of the gentrification may need more than a dichotomous Black-White framework; an interactive combination between race and income (or poverty) may need to be considered.

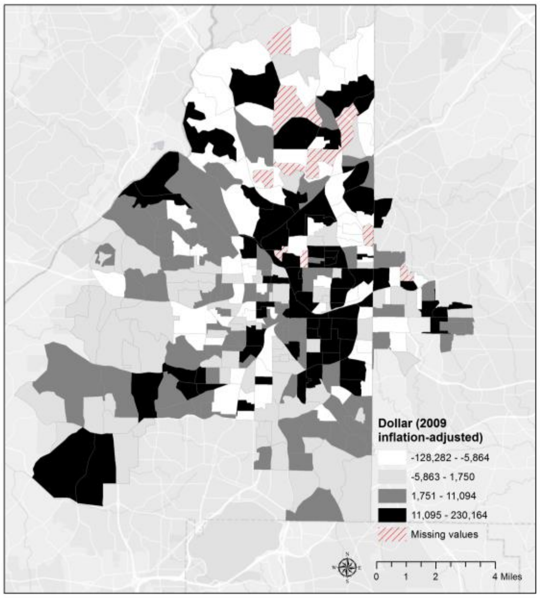


Figure 18. Change in Median Household Income between 2000 and 2009 (African-American)

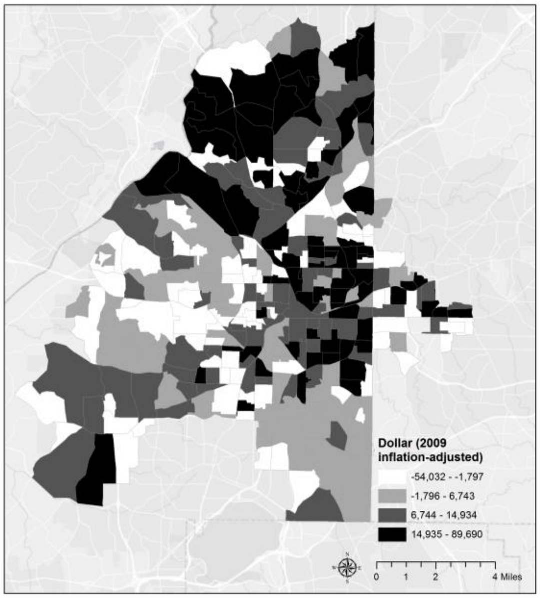


Figure 19. Change in Median Household Income between 2000 and 2009 (All racial groups)

From the perspective of environmental equity, these changing socioeconomic geography can have important implications. In 2000, the predominantly White block groups in the northern half of the city had the highest percentage of residential tree cover in residential areas. The southern half of the city, which has traditionally been African-American neighborhoods, had relatively less residential tree canopy. The inner-city area was the hot spot of vulnerability in which the lack of tree canopy, the concentration of poverty, and a high share of African-American population co-existed. The changes in the distribution of socioeconomic classes/racial groups suggest that the formerly accepted ways in which environmental inequity arises may not be applicable in the same way as it has been, at least in regards to urban tree canopy. The discussions above showed that those who were relatively affluent, well-educated, or White had increased in block groups that had distinctively less urban tree canopy (environmental amenity) in 2000. On the other hand, block groups that had seen an increase in urban tree cover are generally concentrated in the southern half of the city, which has been traditionally African-American, low-income block groups. In short, there appear to have been movements of race, wealth, and poverty that may have alter the relationship between socioeconomic status and urban tree canopy than previously reported in the literature.

4.3 Cross-sectional Model for 2000

The analyses presented in the previous section are descriptive in nature and statistical validity of the arguments is less clear. To test the hypotheses posed in the introduction section and better understand quantitatively the role of individual variables on the relationship between urban tree canopy and socioeconomic variables, the following section of this study shows the results from the three regression models.

Table 6 shows the regression result for the year 2000. Based on the Lagrange Multiplier Test results, the spatial lag model was selected for this cross-sectional model. The spatial autoregressive coefficient was large and significant (Rho in table 6, $p < 0.001$). The adjusted R^2 of OLS model with same variables and structure, which was generated as a comparison to determine the model fit for SAR model, was 0.741, suggesting a good model fit. Akaike Information Criteria (AIC), which provides a relative measure of model fits amongst models being compared, indicates that the SAR model shows better fit than OLS models (the result of OLS model is omitted in the table).

The result of the cross-sectional regression for the year 2000 shows estimates with directions that generally agree with past findings. The variables representing the built environment characteristics are all significant and negatively associated with urban tree canopy except for land use diversity. Median building age and its quadratic term are highly significant with expected signs. The negative coefficient of the quadratic term suggests a downward concave curve, indicating that urban trees in residential areas increase at a faster rate in block groups with newer buildings than those with older buildings. After controlling for built environment and building age, the proportion of African-American, Hispanic or

Latino, residents under poverty are negatively associated with urban tree cover with statistical significance at $p<0.05$. These socioeconomic indicators are generally considered as those characterizing lower adaptive capacity in vulnerability discourse. The percentage of home ownership ($p<0.001$) and the percentage of age 0 to 4 ($p<0.1$) were positively associated with urban tree canopy. Considering that the percentage of home ownership is positively correlated with median household income (Pearson's correlation coefficient 0.581, $p < 0.001$), all variables except the percentage of age 0 to 4 are suggesting that environmental inequity were present in 2000.

The z-statistic values can provide understandings on the relative importance of independent variables (Landry and Ckakraborty, 2009). Among all independent variables, median building age has the highest z-statistic value, followed by percent home ownership, median building age squared, intersection density, percentage of African-American, percentage of Hispanic or Latino, population density, percent under poverty and the rest. The independent variables with high z-statistic values are a mix of socioeconomic variables and physical environment-related variables. It indicates both socioeconomic indicators and physical environment-related indicators are equally strong predictors of urban tree cover.

The significance of racial groups in explaining the uneven geography of urban trees may indicate that other socioeconomic indicators excluded in the regression due to multicollinearity with race may relate to urban trees in similar manners. These covariates of race include housing value, poverty, income, and educational attainment, to name some. Table 7 shows correlations between White, African-American, and Asian, and other generally used indicators of socioeconomic status. The proportion of White and African-American is almost perfectly correlated with a negative sign (Pearson's correlation=-0.982, p <0.000), suggesting that these two racial groups together comprise the majority of the population. The proportion of these two racial groups in a neighborhood, in turn, is closely correlated with education, poverty, income, and housing value, all of which have opposite signs for White and African-American. The proportion of Asian and Hispanic, which are the racial groups that rank third and fourth in population size, has nearly no correlation with socioeconomic status except 'percent limited English' for Hispanic or Latino. Although these correlations may not be useful in understanding the size of the effect as well as its statistical significance for each variable excluded in the regression, they may be helpful in conjecturing the direction of the effect.

Table 6. Cross-sectional SAR_{lag} model result for year 2000

Dependent Variable = Residential tree canopy	Estimate	Std. Error	z value	P value	
Rho (spatial autoregressive coefficient)	0.5997	0.043	13.808	0.000	***
(Intercept)	-0.0138	0.040	-0.344	0.731	
Land use diversity	-0.0123	0.017	-0.709	0.478	
Intersection density	-0.0004	0.000	-3.632	0.000	***
Population density (acre)	-0.0033	0.001	-2.642	0.008	***
Percent age 0 to 4	0.2663	0.155	1.718	0.086	*
Percent age 65 and over	0.0034	0.063	0.055	0.956	
Percent African-American	-0.0526	0.016	-3.328	0.001	***
Percent Asian	0.0233	0.123	0.190	0.849	
Percent Hispanic/Latino	-0.1693	0.059	-2.856	0.004	***
Percent in poverty	-0.0824	0.039	-2.126	0.034	**
Percent home ownership	0.1376	0.024	5.627	0.000	***
Median building age	0.0113	0.002	6.482	0.000	***
Median building age2	-0.0001	0.000	-5.567	0.000	***
Adj R^2 for OLS: 0.741	* p<0.1, ** p<0.05, *** p<0.01				
AIC for OLS: -574.19					
AIC for SAR: -701.68					

Table 7. Correlation between racial groups and socioeconomic status in 2000

	Percent White	Percent African American	Percent Asian	Percent Hispanic
Land use diversity	0.018	-0.061	0.168	0.206
Intersection density	-0.170	0.154	0.019	-0.035
Population density (acre)	-0.064	0.039	0.059	0.088
Percent age 0 to 4	-0.375	0.377	-0.208	0.008
Percent age 65 and over	-0.105	0.142	-0.202	-0.172
Median age	0.209	-0.154	-0.184	-0.198
Percent White	1.000	-0.982	0.246	0.096
Percent African-American	-0.982	1.000	-0.367	-0.256
Percent Asian	0.246	-0.367	1.000	0.283
Percent Hispanic/Latino	0.096	-0.256	0.283	1.000
Bachelor's degree or higher	0.926	-0.892	0.183	-0.022
Percent limited English	-0.003	-0.156	0.374	0.887
Percent in poverty	-0.619	0.591	-0.004	-0.023
Median room number	0.142	-0.085	-0.266	-0.154
Median household income	0.729	-0.702	0.038	0.052
Median housing value	0.879	-0.863	0.164	0.065
Percent home owner	0.235	-0.167	-0.220	-0.235
Median building age	0.086	-0.065	-0.111	-0.062

4.4 Longitudinal Model Between 2000 and 2009

For the longitudinal model, the spatial error model was selected over the spatial lag model based on the Lagrange Multiplier Test. As was observed in the cross-sectional model, the longitudinal model between 2000 and 2009 showed that spatial autoregressive coefficient was large and significant (Lambda in table 8, $p < 0.001$). The adjusted R^2 of OLS model was 0.944, a significantly high value. However, note that inclusion of tree cover in residential areas in 2000 may be considerably contributing to high R^2 value. The AIC value confirmed that SAR_{error} model has better model fit than OLS models (the result of OLS models are not included in the table). The change in residential area between 2000 and 2009 is included in the model to control the possible confounding effect of increase or decrease of residential areas in which urban tree cover was measured. As expected based on the changes in racial redistributive trends in Atlanta, there was an interaction effect observed between the change in African-American and the change in percent poverty. This interaction adds an insight to how the relationship between urban trees and socioeconomic characteristics has changed over time.

The urban tree canopy in residential areas in 2000 was positively associated with that in 2009. The change in total area of residential land uses within block groups are negatively associated with the change in percent tree cover. The negative sign of this coefficient can be interpreted as follows: an increase in residential area may indicate new residential developments in lands that were previously used as other land uses, and urban trees in such areas are likely to be newly planted, younger, and smaller trees. Among the built environment variables, land use diversity in 2000, its change between 2000 – 2009, and the change in intersection density have significant and negative associations with the change in urban tree canopy. Contrary to the cross-sectional model for the year 2000, the result of the longitudinal model showed changing trend in the relationship between urban tree cover and socioeconomic indicators. In the model without the interaction term, the percentage of African-American and Asian in 2000 was positively associated with the future urban tree cover. It indicates that with all other variables held constant, the higher share of these racial groups in the past was a fair predictor of increased urban tree cover in the future. However, the effects of the change in the proportion of racial groups were insignificant in the longitudinal model regardless of racial groups. In the interaction model, the change in the percentage of residents with bachelor's degree or higher was in negative association ($p < 0.05$) whereas percent under poverty was positively associated with urban tree cover ($p < 0.1$). These results are partly suggesting an improvement in environmental inequity in some aspects.

Table 8. Longitudinal SAR$_{error}$ model result with the interaction (2000 ~ 2009)

	Dependent Variable = Tree cover in residential area in 2011	Without Interaction		With Interaction	
		Estimate	Sig.	Estimate	Sig.
	Lambda (spatial autoregressive coefficient)	0.434	***	0.432	***
		(5.796)		(5.796)	
	(Intercept)	-0.012		-0.0117	
		(-0.385)		(-0.386)	
	Tree cover in residential area in 2000	1.083	***	1.0795	***
		(37.337)		(37.499)	
Δ	Total area of residential area	-0.286	***	-0.2911	***
		(-5.898)		(-6.052)	
	Land use diversity in 2000 (z-score)	-0.018	***	-0.0188	***
		(-4.680)		(-4.818)	
Δ	Land use diversity (z-score)	-0.011	***	-0.0109	***
		(-2.772)		(-2.840)	
	Intersection density in 2000 (z-score)	-0.002		-0.0044	
		(-0.325)		(-0.777)	
Δ	Intersection density (z-score)	-0.011	**	-0.0106	**
		(-2.394)		(-2.378)	
	Population density in 2000 (Acre)	-0.000		-0.0002	
		(-0.724)		(-0.280)	
Δ	Population density (Acre)	-0.000		-0.0004	
		(-0.122)		(-0.427)	
	Percent age 0 to 4 in 2000	-0.140		-0.1625	
		(-1.354)		(-1.579)	
Δ	Percent age 0 to 4	-0.140	**	-0.1356	**
		(-2.398)		(-2.346)	
	Percent age 65 and over in 2000	-0.022		-0.0253	
		(-0.523)		(-0.603)	
Δ	Percent age 65 and over	0.110	***	0.1095	***
		(2.730)		(2.744)	
	Percent African American in 2000	0.040	*	0.0430	**
		(1.849)		(1.987)	
Δ	Percent African American	0.021		-0.0161	
		(0.777)		(-0.499)	
	Percent Asian in 2000	0.148	*	0.1378	
		(1.751)		(1.639)	
Δ	Percent Asian	0.067		0.0212	
		(0.883)		(0.270)	
	Percent Hispanic/Latino in 2000	-0.001		0.0019	
		(-0.023)		(0.043)	
Δ	Percent Hispanic/Latino	0.022		-0.0032	
		(0.499)		(-0.072)	
	Percent pop. with bachelor's degree or higher in 2000	-0.007		-0.0055	
		(-0.272)		(-0.204)	
Δ	Percent pop. with bachelor's degree or higher	-0.041		-0.0531	**
		(-1.590)		(-2.011)	

	Percent in poverty in 2000	0.027		0.0270	
		(1.048)		(1.048)	
Δ	Percent in poverty	0.058	***	0.0403	*
		(2.833)		(1.852)	
	Percent home ownership in 2000	0.008		0.0074	
		(0.545)		(0.494)	
Δ	Percent home ownership	0.013		0.0156	
		(0.594)		(0.737)	
Δ	Interaction:			-0.1861	**
	Percent African American*Percent in poverty	-		(-2.202)	
Adj R^2 for OLS		0.944		0.945	
AIC for OLS		-886.56		-888.91	
AIC for SAR		-903.56		-906.37	

* In parenthesis are z-statistic values
* Variables denoted by Δ represent the difference between 2009 and 2000
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

The interaction term composed of the change in the proportion of African-American and the change in the poverty rate was significant at $p < 0.05$. Figure 20 and 21 show how the effect of additional change of poverty rate or the change in the proportion of African-American varies depending on the value of the other. As the value of the change in the percentage of African-American moves from its second quantile value of -0.206 to ninth quantile value of 0.048, the slope for the change in percent under poverty varies from steep to modest upward slopes. Conversely, as the value of the change in the poverty rate moves from its second quantile value of -0.176 to ninth quantile value of 0.176, the slope for the change in the percentage of African-American varies from upward slope to downward slope. As shown in figure 21, these lines cross in the middle, explaining the reason for the insignificance of the change in the percentage of African-American. The crossing lines mean the percentage of African-American has opposite effect on the urban tree cover depending on the value of the change in the poverty rate. The change in poverty rate alone was significantly associated with an increase in urban tree cover regardless of the values of the percentage of African-American, but its magnitude varied depending on the value of the change in the proportion of African-American. In short, an increase in poverty was associated with an increase in urban tree cover with its magnitude varying depending on how the percentage of African-American changed. An increase in the proportion of African-American was associated with an increase in urban tree cover if the block group had reduced its poverty rate; if the poverty rate was increased, a higher proportion of African-Americans was associated with a reduction in urban tree cover.

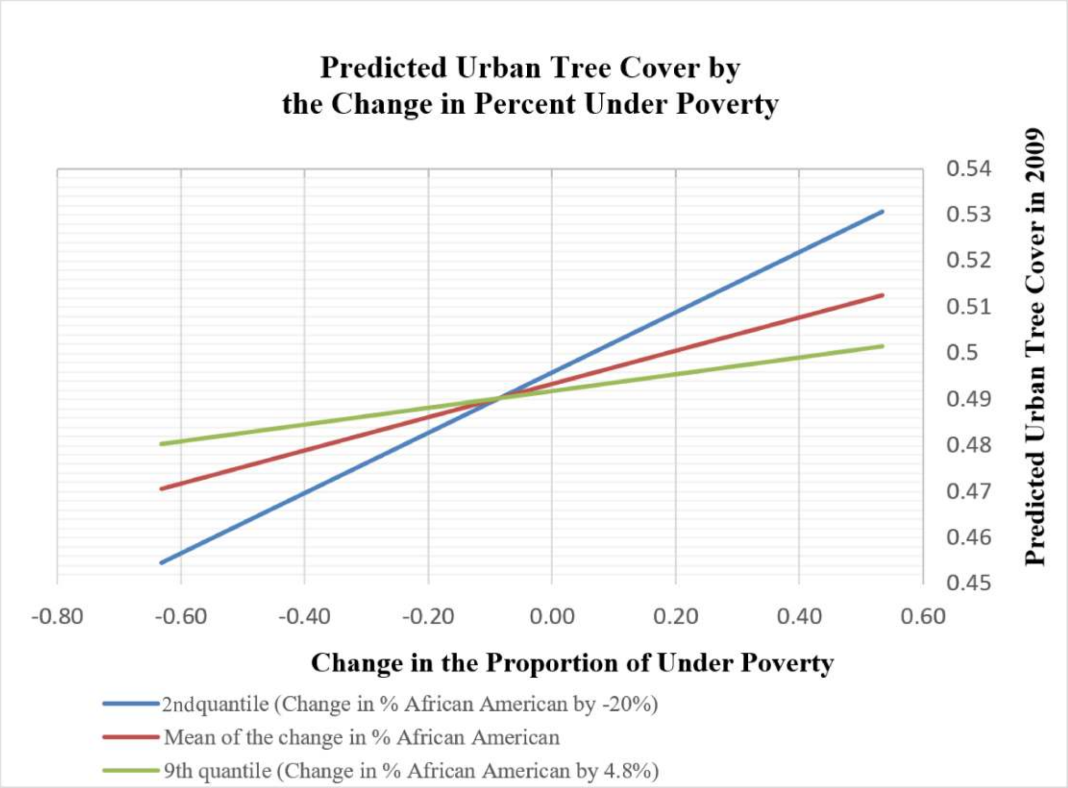


Figure 20. The Effect of the Change in Percent Under Poverty on Predicted Urban Tree Canopy in 2009 Depending on the Change in Percent African American

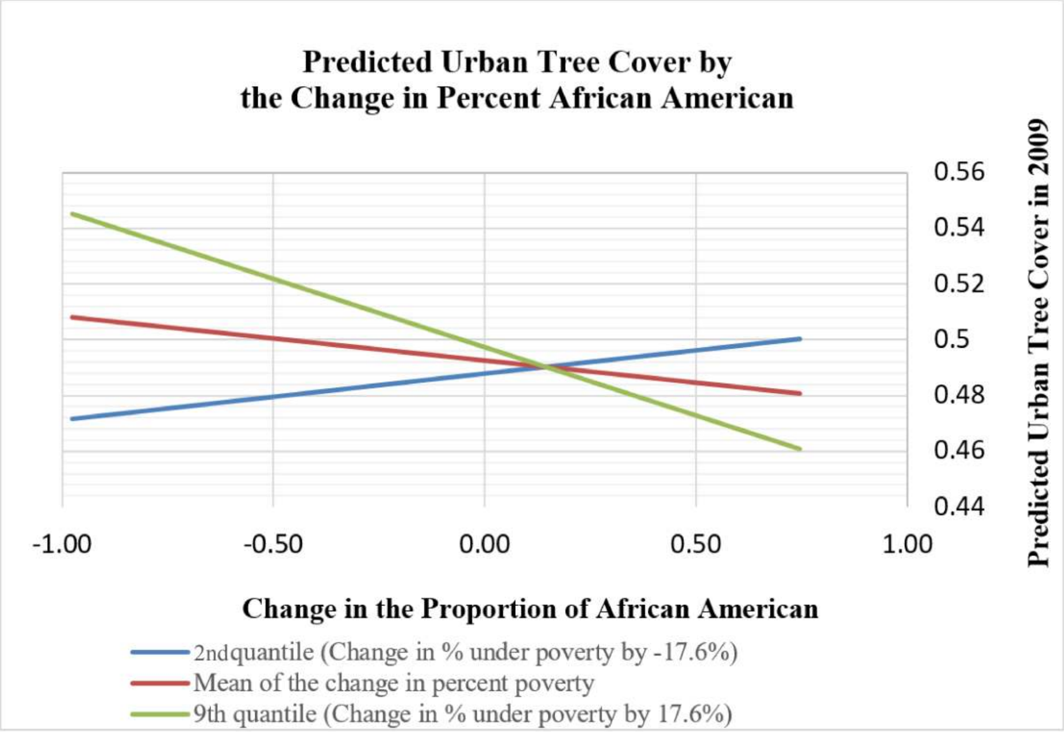


Figure 21. The Effect of the Change in Percent African American on Predicted Urban Tree Canopy in 2009 Depending on the Change in Percent Under Poverty

The z-statistic values suggest that tree canopy in 2000 is by far the strongest predictor of the change in tree canopy, followed by the change in the total area of residential uses, land use diversity in 2000, the change in land use diversity, the change in the proportion of age over 65, the change in intersection density, the change in the proportion of age 0 to 4, the interaction term, and the rest. Among the socioeconomic variables, the change in age-related variables were the strongest predictors of higher urban tree cover. The result of the longitudinal model suggests that the dynamic between the distribution of urban trees and socioeconomic status has become more complex than what was reported in past studies or in the cross-sectional model for 2000.

4.5 Cross-sectional Model for 2013

Table 9 show the regression result for the year 2013. Based on the Lagrange Multiplier Statistic values, the spatial lag model was selected. The spatial autoregressive coefficient was large and significant (Rho in table 9, $p < 0.001$). The adjusted R^2 of OLS model with same variables and structure was 0.695, suggesting a good model fit. AIC values indicate that SAR model (AIC = -638.41) shows better fit than OLS models (AIC = -498.16). The result of OLS model is omitted in the table.

The cross-sectional regression for the year 2013 showed estimates that conform to Atlanta's racial redistributive trend. The indicators representing the built environment characteristics, land use diversity, intersection density, and population density, were all significant at $p<0.05$ and negatively associated with urban tree canopy. Median building age and its quadratic term were highly significant with expected signs, indicating a downward concave curve. After controlling for built environment and building age, the proportion of age over 65, African-American, home ownership ($p<0.05$), and Asian ($p<0.1$) were positively associated urban tree cover. The poverty rate, however, had a negative coefficient at $p < 0.1$. These results expand the findings from the longitudinal model that racial minorities in the model, particularly African-Americans, were no longer a significant predictor of environmental inequity but rather a predictor of more urban tree cover. Despite the positive effect of the change in the poverty rate in the longitudinal model, the poverty rate was still a significant predictor of less urban tree cover. Home ownership was positively associated with urban tree cover, indicating that greater economic resource was a significant predictor of increased urban tree cover.

Table 9. Cross-sectional SAR_{lag} model result for year 2013

Dependent Variable = Tree cover in residential area	Estimate	Std. Error	z value	P value	
Rho (spatial autoregressive coefficient)	0.6311	0.042	14.751	0.000	***
(Intercept)	0.1416	0.039	3.662	0.000	***
Land use diversity	-0.0701	0.020	-3.575	0.000	***
Intersection density	-0.0001	0.000	-3.392	0.001	***
Population density (acre)	-0.2375	0.043	-5.524	0.000	***
Percent age 0 to 4	0.0932	0.106	0.883	0.377	
Percent age 65 and over	0.1451	0.059	2.449	0.014	**
Percent African American	0.0533	0.019	2.847	0.004	***
Percent Asian	0.2058	0.111	1.860	0.063	*
Percent Hispanic/Latino	0.1054	0.068	1.540	0.124	
Percent in poverty	-0.0715	0.038	-1.878	0.060	*
Percent home ownership	0.0811	0.026	3.111	0.002	***
Median building age	0.0014	0.000	4.900	0.000	***
Median building age2	-0.0000	0.000	-5.352	0.000	***
Adj R^2 for OLS: 0.695 AIC for OLS: -498.16 AIC for SAR: -638.41	* p<0.1, ** p<0.05, *** p<0.01				

CHAPTER 5. DISCUSSION

This study examined cross-sectional and longitudinal trends of environmental inequity in Atlanta by analyzing the relationship between urban tree canopy distribution and socioeconomic indicators. In a cross-sectional model for 2000, racial minorities, economically disadvantaged, and renters have lower urban tree canopy than their counterparts, supporting the inequity hypothesis. In the longitudinal model, however, the inequity appeared to be improving in some aspect of socioeconomic status. The interaction term in the model revealed that the coefficient of the change in the percentage of African-American can have opposite direction depending on the change in the poverty rate. In 2013, race is no longer a significant predictor of environmental inequity, but rather a factor that is associated with an increase of urban tree canopy if it is African-American and Asian. Nonetheless, poverty and home ownership had consistent effect contributing to environmental inequity. For vulnerable age groups, the age cohort in positive associations with urban tree canopy had changed between 2000 and 2013.

The results from the regression models align with the racial/economic redistributive trend in Atlanta. As shown in previous chapters, it is the inner-city areas in which urban trees are most sparsely distributed that have been welcoming an influx of higher socioeconomic classes, many of whom were Whites. These neighborhoods include Home Park, Downtown, Cabbage Town, Old Fourth Ward, and Midtown, all of which are in close proximity to Downtown and have relatively less urban tree canopy. This trend appears to have blurred once-evident relationship between racial minority and urban tree cover. At the same time, a large fraction of African-American residents moved from the inner-city areas to outskirts of the city. These areas tend to have higher urban tree canopy than the inner-city areas. The regression result also showed that block groups that had a greater share of African-American or Asian in 2000 had seen an increase in urban tree cover between 2000 and 2011. These trends may have been a reason for the positive coefficient for the proportion of African-American and Asian in 2013.

As a simplified illustration of how socioeconomic variables relate to residential tree cover in 2000 and 2013, table 10 shows the mean or median values of some of key explanatory variables by the urban tree canopy gradient partitioned in quantiles for block groups within the city boundary (figure 22 is a graphical illustration of table 10). Note that due to changes in urban tree canopy, quantiles in 2000 may be different from 2013. Thus, the same census tract can be allocated into different quantiles in 2000 and 2013. In 2000, the share of White was the lowest in block groups with the lowest tree canopy and gradually increased as the tree canopy increased. Conversely, that of African-American showed the opposite pattern with the highest share found in the areas with the lowest tree canopy.

In 2013, these curves nearly flipped: the greatest share of White could be found in the second quantile region, which it is close enough to the central business district but not 'at the center'. These were the block groups that had the lowest proportion of African-American population. The way in which the White curve changed between 2000 and 2013 closely resembles that of median housing value and, to a less extent, median household income. The proportion of residents with bachelor's degree or higher also appears to have changed in a pattern similar to that of percent White. In both 2000 and 2013, the poverty rate is clearly high in areas with the least urban tree cover but the areas with the least poverty moved from the fifth quantile to the second. The home ownership, and the proportion of residents aged 0 to 4, and the proportion of residents aged 65 and over did not change as dramatically as other variables.

Table 10. Mean or Median of Explanatory Variables by Urban Tree Canopy in Quantiles

	Less Tree Cover	<==================	==>	More Tree Cover	
	Quant 1	Quant 2	Quant 3	Quant 4	Quant 5
% Age 0 to 4	6.5%	6.2%	6.6%	6.1%	5.9%
	5.0%	6.1%	7.3%	7.8%	6.7%
% Age 65 and above	9.1%	9.8%	11.3%	10.9%	12.8%
	6.8%	9.9%	11.0%	12.3%	15.6%
% White	18.9%	22.3%	23.2%	35.2%	59.2%
	38.7%	54.2%	41.0%	40.0%	22.4%
% African American	74.2%	73.0%	71.8%	60.7%	37.7%
	50.4%	39.0%	39.0%	55.6%	74.6%
% Asian	2.4%	1.9%	1.6%	0.9%	1.2%
	6.2%	3.5%	3.5%	1.2%	1.1%
% Hispanic	5.0%	3.5%	4.4%	3.6%	2.4%
	6.6%	5.7%	5.7%	4.5%	2.4%
% Bachelor's degree or higher	20.1%	21.7%	22.4%	34.3%	52.4%
	47.8%	52.9%	52.9%	40.7%	35.7%
% Under poverty	42.0%	28.6%	23.5%	18.5%	11.1%
	33.1%	20.7%	24.1%	24.6%	25.3%
% Owner-occupied housing	16.5%	37.3%	46.1%	56.5%	69.6%
	25.2%	43.6%	43.6%	54.2%	61.7%
Median building age (year)	38	46	43	40	40
	21	49	58	54	46
Median household income ($)	20,369	29,875	32,575	44,150	76,952
	41,290	58,240	60,660	57,690	66,380

Note. Due to changes in urban tree canopy, quantiles in 2000 may be different from 2013. Thus, a neighborhood or a census tract can be allocated into different quantiles in 2000 and 2013.

White = 2000 data
Grey = 2013 data

In sum, distributions of many, if not all, socioeconomic indicators in 2000 followed the distribution of urban tree canopy – areas with greater tree canopy were better off than areas with less tree canopy. In 2013, areas with the lowest tree canopy were still showing low socioeconomic status but areas with the second-lowest tree canopy were showing the greatest performance in some socioeconomic indicators such as median housing value, educational attainment, and poverty rate.

Note that this change from 2000 to 2013 is not only caused by the changes in the geography of socioeconomic statuses but also by changes in residential tree canopy. As shown in figure 5 to 8 in Section Four, the tree canopy in the northern part of the city, which has been predominantly White neighborhoods, had declined whereas that in the southern part of the city, which has been largely African-American areas, had increased. This can be interpreted as, for example, some of the northern block groups that were included in the 5th quantile (the lushest area) in 2000 were classified into quantiles with less tree canopy. Conversely, some of the block groups in the southern half of the city that were in quantiles with less tree canopy moved into the 5th quantile. Thus, table 10 and figure 22 should be understood as the result of the combination of changes in both tree canopy and socioeconomic statuses.

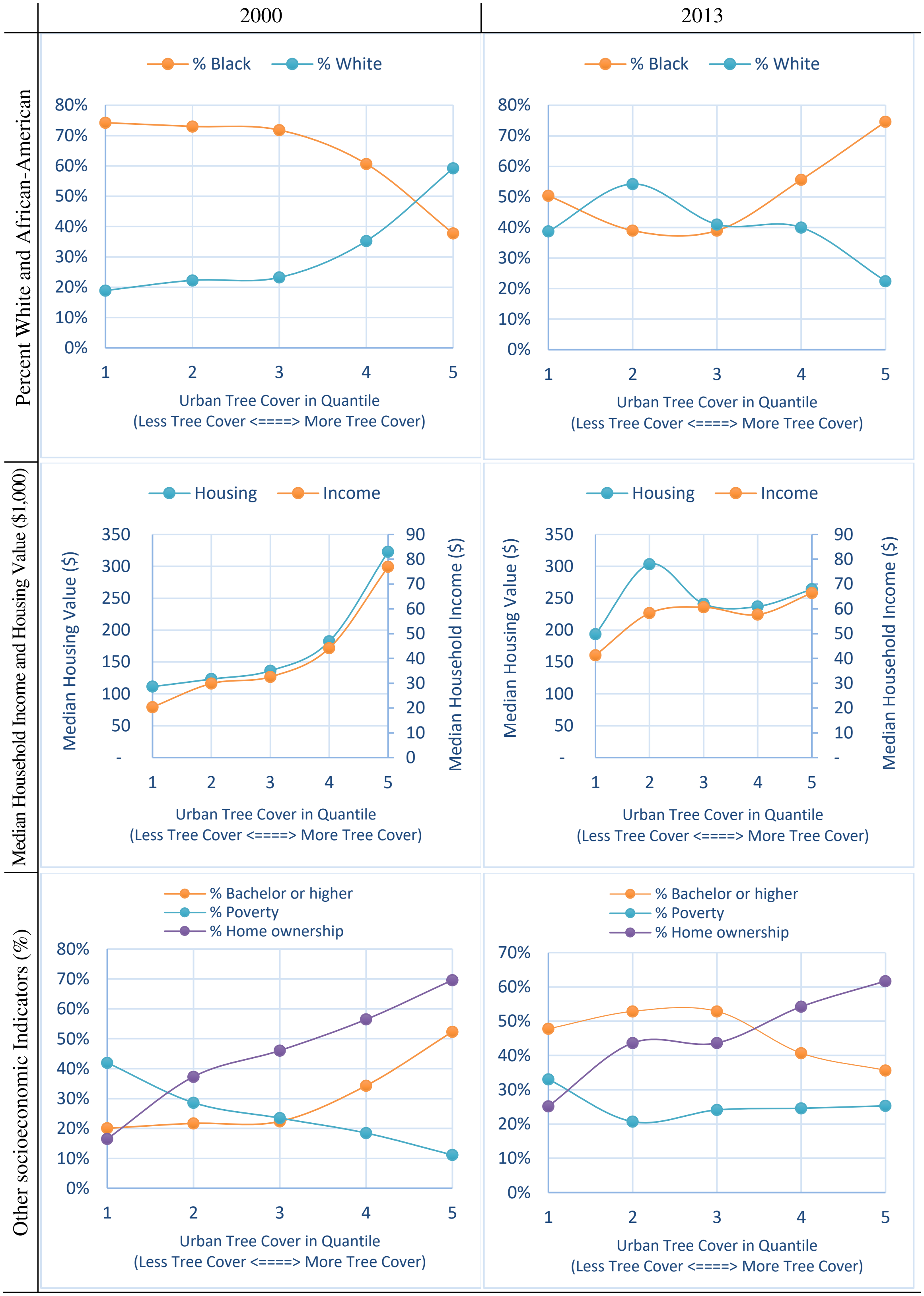


Figure 22. Socioeconomic Indicators by the Quantiles of Residential Tree Canopy

An attempt to reveal the reason why higher socioeconomic classes or Whites had increased in areas with less tree canopy is out of the scope of this study. However, there are indications in the literature that provide some potential explanations for this trend: changes in the preference for residential locations. Literature has documented the shifting preference of residential locations toward more walkable urban forms, which resulted in an increase in property value and a decrease in affordability (Talen, 2013). Assuming this change in the preference occurred regardless of demographic or socioeconomic classes, it is plausible that neighborhoods that satisfy the new preferences would be occupied by those who can outbid others. A survey conducted in metropolitan Atlanta area in 2004 showed that "a significant proportion of Atlanta area residents would prefer to live in a community that affords an increased ability to walk to nearby shops and services, and shorter travel distances to work, even if it meant smaller lots and through traffic on their streets" (Frank, Chapman, and Levine, 2004, 8). The survey also revealed that the preferences on neighborhoods are not statistically different amongst different ethnic groups, and that there was undersupply of such communities that those who were looking for less auto-oriented communities end up in less optimal choices. Note that the built environment-related variables of this study – land use diversity, intersection density, and population density – showed statistically significant and negative associations with urban tree canopy. Land use diversity, intersection density, and (residential) density has been used to construct the walkability index, which measures how conducive the built environment is for walking (Frank et al., 2005).

The BeltLine project might have played a role in supplying such communities in the region, drawing those who have resources to realize their preferences. The well-educated, relatively high-income residents, who are often Whites, are likely to be able to outbid others in neighborhoods that provide transit-oriented, walkable, and park- and trail-friendly environments. Most of the BeltLine segments are in the second quantile of urban tree canopy distribution – the area with the highest share of White, the most expensive housing units, the most well-educated residents in 2013. For some block groups, the BeltLine is the dividing line between the first and second quantile areas.

Past studies have reported a greater urban tree cover in neighborhoods with the higher proportion of home ownership (Heynen, Perkins, and Roy, 2006; Landry and Chakraborty, 2009). These studies explained that homeowners have greater motivations to invest in their property for increased property value through tree plantation or maintenance. As mentioned in the previous section, urban trees are associated with increased property value. Renters, on the other hand, may be less willing to spend their resources to contribute to the property. The results from the two cross-sectional models indicated that the share of homeowners are a strong predictor of greater urban tree cover. Additionally, the proportion of home ownership in Atlanta was associated with higher median household income in 2000 (Pearson's correlation coefficient 0.581, $p<0.000$) and 2013 (Pearson's correlation coefficient 0.652, $p<0.000$), which is known to be another strong predictor of urban tree cover (Landry and Chakraborty, 2009; Lowry, Baker, and Ramsey, 2012). Figure 23 is the scatterplots showing the relationship between the proportion of home ownership and median household income in 2000 and 2013. Another explanation is that, due to greater economic resources of homeowners, they are more likely to actively engaged in activities to increase urban tree cover within or around their property because they can afford it. Similarly, Pham et al. (2012) argue that local actors have fewer initiatives for tree plantation in low income, low-vegetated areas (222).

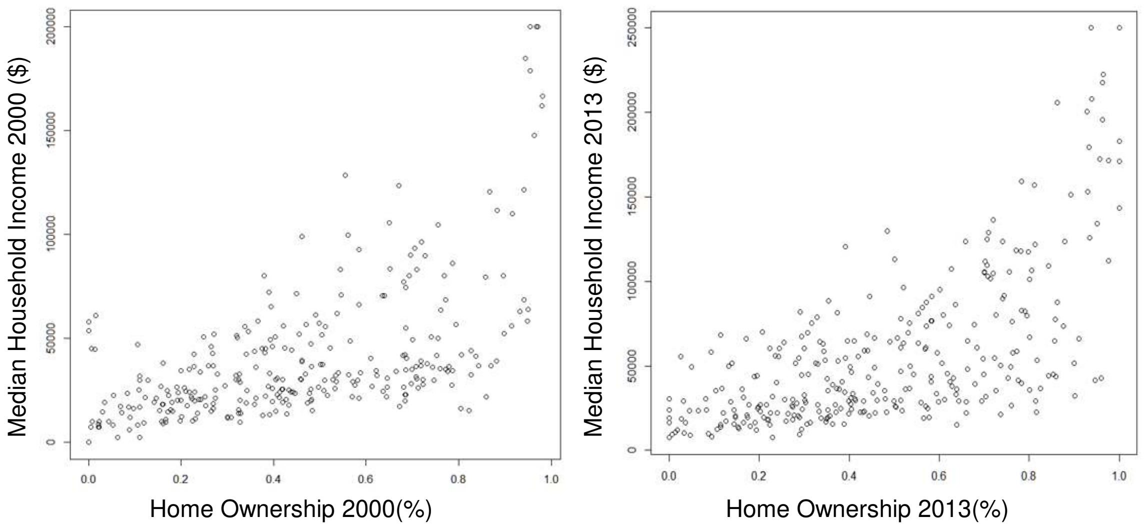


Figure 23. Relationship between the Proportion of Home Ownership and Median Household Income in 2000 (left) and 2013 (right).

The poverty rate has consistently been a predictor of inequitable distribution of urban tree cover in 2000 and 2013. Despite the fact that the longitudinal analysis between 2000 and 2009 indicates that the increase in urban tree cover had occurred in favor of racial minority and those in poverty, the effect of poverty rate persisted with statistical significance at $p<0.1$. Confounding the intuitive interpretation of the effect of poverty is that there was a high correlation between African-Americans and the poverty rate, and that the proportion of African-American and poverty were associated with urban tree cover in the opposite direction. One explanation for this result is that African-American population has been rapidly increasing in suburban areas in which 87% of African-Americans were living in 2010 (Pooley, 2015), and there were considerable differences in income between African-Americans (or other racial minorities) in suburbs and inner city areas, with those in inner city areas having lower income and less likely to be professionals (Clark, 2009; Strait and Gong, 2015). Although tentative, it can be hypothesized that there may have been a stronger economic and geographic stratifications within African-Americans. Similar to the findings of this studies, past studies reported greater degrees of association between economic disadvantages and lower levels of urban tree cover than between racial minority and tree cover (Landry and Chakraborty, 2009; Pham et al., 2012).

From the perspective of vulnerability theory, the results of this study indicate that the relationship between vulnerable population and the risk moderator has been changing towards more complex, multi-faceted direction. The longitudinal model indicates that the change in the distribution of urban tree cover was in favor of those who were racial minorities, under poverty, and less educated. Given that these indicators are often used to construct vulnerability index for natural hazards, it can be inferred that those who may have lower adaptive capacity have increased in areas where mitigators for the risk of exposure has increased. In 2013, African-Americans and Asians were associated with higher urban tree cover whereas poverty and home ownership were still significant predictors of vulnerability. Note that although the racial minority has been used as a construct of vulnerability to natural hazards in past studies, it may have been so because of the historical relationship between racial minority and lower socioeconomic status, not because a particular race itself is innately vulnerable to natural hazards. Thus, it is difficult conclude that the evidence of African-Americans and Asians being associated with higher urban tree cover necessarily mean they are generally less vulnerable; it would be more plausible to conclude that race in 2013 may no longer be an accurate proxy of wider vulnerability gap coming from the combination of exposure and adaptive capacity. Nonetheless, the residents in areas with the least urban tree cover are likely to have higher vulnerability due to their economic disadvantages. Furthermore, these factors will render the possibility of an increase in urban tree cover less likely without external interventions. Poverty rate appears to be an effective predictor that can guide future planning and policy decisions. Clearly, the impoverished residents in the city center are likely to be the most vulnerable people because their limited resources can be translated into a lack of adaptive capacity, and sparse urban trees would lead to higher risk of exposure. Additionally, the fact that an improvement in economic status tends to be associated with better health conditions (Kennedy et al., 1998) may indicate that these populations may have higher sensitivity and thus higher vulnerability.

CHAPTER 6. CONCLUSION

Trees tend to stay put once they are planted but people do not. Between 2000 and 2013, Atlanta has seen a dramatic change across the city in terms of its racial composition and their residential locations, which altered the relationship between urban tree canopy and residents' socioeconomic statuses. As the result, the city performs better than before in terms of environmental equity, at least in some aspects. Importantly, many of the previous environmental equity studies on the relationship between urban tree canopy and socioeconomics used cross-sectional framework. Because discussing how to change the residents side of the equation is much less viable in cross-sectional framework, they paid more attention to the 'urban tree canopy' side of the equation than on the 'residents' side and discussed how to increase the urban tree canopy. This study, however, revealed that the relationship can be better understood by paying equal attention to the urban tree canopy side and residents side in a longitudinal perspective.

However, this study is limited in identifying whether the improvements in some aspect of environmental equity was the outcome of purposeful efforts to provide equitable distribution of urban tree cover to disadvantaged residents. Rather, the evidence appear to lend support to the redistributive trend affected by the changing preferences of Atlanta residents that altered residential locations of different socioeconomic classes as the major driver of this improvement. In sustainability discourse, land use diversity, street connectivity, and density are widely endorsed as characteristics of urban forms that promote sustainability (Jabareen, 2006). Such characteristics can reduce vehicle mile traveled, encourage transit use or active transport such as walking and bicycling, reduce obesity and other physical-activity related mortality, and add vitality and diversity to cities (Jacobs, 1961; Jabareen, 2006; Lathey, Guhathakurta, and Aggarwal, 2009; Botchwey, Trowbridge, and Fisher, 2014).

The land use diversity, street density, and population density constantly showed negative coefficients with large z statistic values, indicating that at least a few components of the sustainable urban form are in conflict with urban tree canopy: there may be a trade-off relationship between the benefits of so-called sustainable urban form and tree cover. As the White populations are increasing in the inner-city areas attracted by the proximity to downtown and the amenities associated with it (Aka, 2010), future study will need to disentangling the drivers of improvement or degradation of environmental equity.

A few suggestions for the planners and policy-makers can be derived from this study. The tree canopy assessment in 2001, 2011, and 2013 revealed that some areas, particularly the inner-city areas, have constantly lacked urban tree canopy regardless of year. To increase the tree canopy in such areas to desirable level, the city of Atlanta can consider leveraging its tree protection ordinance to prioritize the planting of new trees in areas that lack the tree canopy the most. One approach would be to allow replacement trees to be planted in places outside of its original NPU and direct them to areas that lack urban tree canopy the most. The series of regression results and descriptive statistics indicate that the inner-city area remains as a hot spot where the high poverty rate, as well as high rentership and lack of urban tree canopy, co-exist. In a long-term perspective, an incentive-based approach aimed at increasing planting places in dense urban cores may also be considered. The privately owned public space, for example, can be a useful policy tool. In this policy tool, a city offers zoning concessions (i.e., bonuses on floor area ratio) to developers who agree to provide public spaces in their lots (Kayden 2000), which can provide additional planting spaces in areas with high property value or where there are development pressures. Note that this approach will require a careful examination of the trade-offs between increased building density/volume and the benefits from the additional trees, which calls for future research.

Given that the percentage of African-American or Asian was associated with higher urban tree canopy in 2013, the maintenance of existing trees can have growing importance. Past studies presented that, if not maintained properly, trees growing along the fence line in private yards can be considered as nuisance and liability (Heynen, Perkins, and Roy, 2006). In Milwaukee, many of these large, under-maintained trees in minority neighborhoods are removed at a rate faster than other intentional plantations (Heynen, Perkins, and Roy, 2006). Because the maintenance requires resources, Heynen, Perkins, and Roy (2006) write, “wide-scale removal of poorly maintained trees may lead to heightened urban-forest inequity between poor African-American sections of the city and wealthier owner-occupied portions” (17). City arborists or tree advocates such as Trees Atlanta can steer the use of their resources more to provide resources and knowledge to assist African-American or Asian sections of Atlanta to minimize urban tree canopy from being a hazard rather than benefits.

By incorporating the vulnerability theory, this study adds one more dimension to the environmental equity discourse and suggest a framework for the development of future planning/policy-making in a more efficient manner. Given the limitations in resources for new tree plantation, a strategy for prioritization is essential if the optimized result is to be achieved. Currently, the tree protection ordinance of Atlanta considers physical environments that need heat island mitigations or soil stabilizations as planting priority. In addition to these standards, the poverty rate or rentership can be effective criteria that can be used to identify areas where the residents are more vulnerable and thus are in greater needs of the benefits from the trees. For areas that are physically limited in potential planting space such as downtown or midtown, other strategies to provide ecosystem services similar to that of urban tree canopy can be considered. For example, the green roof can provide ecosystem services that are similar to those from urban tree canopy, including storm water management, regulation of building temperature, and reduced urban heat island (Oberndorfer et al., 2007). The green area ratio can be a highly effective approach for this end (Stone, 2012). In 2007, the city of Seattle adopted a landscape standard known as the 'green factor.' Landowners are required to obtain a minimum score of the green factor to get construction permits from the city (The City of Seattle). The green factor scoring strategy includes landscaped areas, plantings, green roofs, vegetated walls, water features, and permeable paving. Another possible approach is to prioritize the installation of cooling centers in such areas. The importance of the access to cooling centers for the vulnerable populations has been discussed in the field of the preventive medicine and public health as well (Luber and McGeehin, 2008). A heat wave warning system and media messages conveying information on the danger of heat can also be considered (Ibid). These alternative approaches gain more importance considering the fact that, first, the inner-city areas still have high poverty rate which may translate into the low adaptive capacity and second, even if sufficient levels of tree plantation occur in these vulnerability hot spots it will take many years for the newly planted trees to grow and be able to provide shading and other benefits.

Finally, it is important to clarify limitations associated with the methodology used in this study. First, the temporal difference in the longitudinal model between NLCD 2011 and American Community Survey 2009 may have introduced some bias in the results of the analysis. Second, this study uses urban tree cover to proxy its benefits. Considering the benefits of urban trees may vary depending on various factors including their species or health status, actual measurements of the benefits will strengthen the implications of a study. Third, this study did not take into account the benefits of urban trees that are experienced at non-home context. Throughout the course of a day, people engage in various activities in different locations and the level of appreciation of benefits of urban trees may vary accordingly. By tracking the movements of people across time and space, and by matching them with actual measurements of the benefits of urban trees, a more accurate understanding of the environmental equity will be acquired. Fourth, this study did not consider biophysical conditions on which lives of urban trees heavily depend. Finally, this study focused on dismantling the relationship between the movement of residents with various demographic and socioeconomic indicators and thus is limited in understanding what caused the change in the distribution of tree canopy over time. Future research can build on the findings and limitations of this study to better formulate pathways toward an equitable and resilient city.

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