AN ABSTRACT OF THE ESSAY OF

Victoria Venable for the degree of Master of Public Policy presented on May 17, 2021.

Title: EVALUATING THE SOCIAL EQUITY IMPLICATIONS OF GREEN INFRASTRUCTURE FOR URBAN RESILIENCE

Abstract approved

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As the threat of climate change becomes more imminent and the role of cities in climate adaptation becomes clearer, urban resilience, the ability of a city or urban system to withstand a wide array of shocks and stresses, has gained increasing attention in climate adaptation policy and planning. Critics of traditional resilience-building investments claim that these policies do not adequately consider power, politics, and justice, therefore preventing systemic change and sometimes even exacerbating social inequities. Using panel data at the census tract level in Washington D.C., Portland, Oregon, and Houston, Texas, this research looks at how green infrastructure flood risk reduction (GI-FRR) projects affect housing affordability between 2010 and 2019. This analysis is supplemented by a qualitative review of each city's climate adaptation plan using the Fitzgibbons & Mitchell (2019) rubric to evaluate how intentionally cities incorporated aspects of justice, equity, and power. Findings indicate that census tracts with newly implemented GI-FRR projects experience increases in household income, housing values, and percentage of people with a bachelor's degree in Portland, Oregon and Washington, D.C. However, there was no significant relationship between green infrastructure implementation and gentrification in Houston, Texas. I also identify that while cities incorporate equity to varying degrees, the outcomes in terms of housing affordability and neighborhood change are not significantly different. These conclusions add insight to climate planning on the city and local level by identifying a critical side effect of building urban resilience without an equity lens: gentrification and a widening resilience gap. Further research should investigate how this relationship extrapolates to other cities with varying zoning policies and of varying sizes and regions as well as considering other resilience programs to better understand the impact of resilience investments on housing affordability and community evolution.

Keywords: green infrastructure, climate resilience, urban resilience, urban planning, gentrification, social equity, environmental justice

EVALUATING THE SOCIAL EQUITY IMPLICATIONS OF GREEN INFRASTRUCTURE FOR URBAN RESILIENCE

by
Victoria B. Venable

AN ESSAY

submitted to

Oregon State University

in partial fulfillment of
the requirement for the
degree of

Master of Public Policy

Presented May 17, 2021
Commencement

Master of Public Policy essay of Victoria B. Venable presented on May 17, 2021

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ACKNOWLEDGEMENTS

I would like to express appreciation for those who helped me accomplish this project and complete my degree. Thank you to Erika Wolters, my committee chair and academic advisor, who provided guidance, support, and invaluable feedback throughout my time at OSU and on this project.

Thank you to my committee members Mark Edwards and Alison Johnston, whose teaching has made me a better researcher, analyst, and writer.

Thank you to Tim Kurtz, Neil Revello, and the City of Portland Bureau of Environmental Services for support in collecting the data needed for this research. Likewise, thank you Steven Johnston and the Houston-Galveston Area Council for their support in data collection.

I would also like to thank my cohort in the School of Public Policy. I have learned an incredible amount from each of you in class discussions, over break-room lunches, in summer book clubs, and on socially-distanced hikes and picnics. Their brilliance and devotion to public service have given me such hope for the future.

Thank you, also, to my friends and family all across the country. My sisters and parents have supported me in everything I have done, and it is because of them that I have become a lifelong learner.

Thank you to my service dog John, who made going back to school possible and who has been by my side for every single moment of this program. I suspect he has earned a degree from OSU in his own right.

Lastly, thank you to my partner and best friend, Nic, who convinced me to go on this adventure and whose love and support have carried me through countless challenges.

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Chapter One

Introduction

As the threat of climate change becomes more imminent and the role of cities in climate adaptation becomes clearer, urban resilience, the ability of a city or urban system to withstand a wide array of shocks and stresses, has gained increasing attention in climate adaptation policy and planning. Common tools for building urban resilience include strengthening infrastructure, improving emergency response, and changing the built landscape to mitigate the impact of climate change and improve a community's ability to respond to it. However, just as climate change threats are not distributed equally, the benefits and tradeoffs of climate adaptation and urban resilience are often not equitably allocated. Much research has been done on the unequal access to climate change protection, but there is also the question of how cities build climate resilience in equitable ways and if resilience-building tools can have negative outcomes for vulnerable communities. Changes to infrastructure and landscapes can dramatically improve the ability of a city to withstand climate threats such as flooding but could create or exacerbate equity issues such as housing affordability. As more cities recognize the threats of climate change to their basic functions and survival and further understand the role cities can have in mitigating the impacts with resilience-building city improvements, it is important to look closely at the ways these policies could further burden vulnerable populations.

This research looks at how cities across the United States approach climate resilience and the outcomes of a resilience-building tool that is growing in popularity but may come with significant tradeoffs—green infrastructure. First, this study uses a justice and equity rubric to

analyze the urban resiliency strategies of three cities—Washington, D.C., Portland, Oregon, and Houston, Texas—with a focus on how effectively they incorporate justice and equity considerations. These cities were purposefully selected because they have experienced climate change impacts such as flooding and extreme weather events, have green infrastructure programs of varied maturity, and have a diversity of approaches to urban zoning. Then, I examine if areas with green infrastructure investments suffer from gentrification, using a panel analysis of census tracts in each city from 2010 to 2019. I hypothesize that census tracts that received green infrastructure will be more likely to gentrify than census tracts that did not receive green infrastructure. Furthermore, I hypothesize that cities with better incorporation of justice and equity in their resiliency strategies will have less significant outcomes of gentrification. While my panel analysis shows that green infrastructure has led to gentrification within three to six years in Portland and Washington DC, this was not the case for Houston. Additionally, the level of gentrification was not evidently related to the inclusion of justice and equity in resiliency strategies.

This paper is organized as follows. Chapter II will provide a review of the relevant literature including climate adaptation and resiliency literature, research on and history of the use of green infrastructure, and an overview of the phenomenon of gentrification. Chapter III will outline the theoretical framework used to develop this research, particularly the environmental justice framework used to develop the justice and equity rubric. Chapter IV will introduce the case studies within this research and provide information about each city's climate threats and green infrastructure programs. Chapter V will outline the data and methodology used in this research and Chapter VI presents the results and findings of the qualitative analysis as well as the

quantitative analysis. Chapter VII lays out the implications of these findings in a discussion that incorporates both methodologies and discusses the limitations of this research as well as the major takeaways and potential policy recommendations. Finally, I conclude with Chapter VIII.

Literature Review

Prior research in green infrastructure, gentrification, and urban planning informs my research questions and guide the selection of variables and the modeling for the analysis. This section aims to provide a succinct background of this literature to give context to this research and the relevance of the methodological choices. This literature review also serves as a theoretical foundation of knowledge for which this analysis builds upon and contributes.

Climate Adaptation and Urban Resilience

Research shows that the threat of climate change is particularly imperative to cities and urban areas due to the high concentration of dwellings, interconnectedness, and dependency on networked infrastructures (Schauser, S., et al, 2010). As more policymakers and researchers are adopting plans and policies to adapt to our changing climate and develop the ability to live within these conditions, the central goal is to reduce community vulnerability to harmful effects of climate change such as sea-level rise, higher average temperatures, and more frequent and intense extreme weather events (Shaftel, & Jackson, 2020). In many ways, climate change is acutely felt on a local scale impacting cities and municipalities because effects such as flooding, food insecurity, and urban heat bubbles, are felt by local functions. Urbanization affects air, water, and soil quality while also increasing impervious surface cover, which further exacerbates climate impacts such as flooding and heatwaves (Maxwell, et al., 2018, p. 440). As communities continue to grow and grapple with uncertainties and challenges like climate change, urban resilience has become an increasingly favored concept (Leichenko, 2011).

The modern theory of resilience originates from studies of ecological systems, particularly that of C.S. Holling who first introduced the terminology (1979) (Folke, 2006). As it

relates to climate adaptation, urban resilience has been understood as the ability of an urban community to withstand chronic and acute stressors and shocks produced by the changing climate; however, the conceptualization and definition of resilience vary dramatically across the literature, providing an opportunity for interdisciplinary collaboration but also troubling ambiguity (Davoudi, et al., 2012, p. 305). In some ways, the malleable nature of the terminology allows for actors from widely varying perspectives to see their interests represented, forming a kind of "boundary object" or "bridging concept" that unifies governing efforts (Fink, 2020, p. 26; Beichler, et al., 2014). This viewpoint stresses that it is the flexibility of the terminology that allows "urban resilience" to resonate with many domains and support the interconnectedness that is necessary for urban resilience (Meerow & Newell, 2019, p. 315).

Alternatively, ambiguity and vagueness around terminology can create problems with operationalizing, prioritizing indicators, and establishing metrics to monitor progress (Vale, 2014). The lack of consensus around the definition of resilience as well as the discourse regarding the role and context of transformation contribute to the criticism that resilience has gained "buzzword" status. Many scholars claim that the concept of resilience has gone the way of "sustainability" and "smart growth," in that the usage of the term is so varied across disciplines and contexts, that it has lost much meaning and instead serves as a buzzword to evoke support for policy initiatives without much substance behind the term (Vale, 2014, p. 196). Porter and Davoudi (2012) warn that resilience may become a "hollow concept for planning," while other scholars stress that the usage of the word is more dubious, used as a mechanism to justify urban capital accumulation and revitalization that works hand-in-hand with the neoliberalism agenda (p. 329; Garcia-Lamarca, et al., 2019, p. 4). It is particularly relevant that

many of these scholars identify the housing cost increases that often accompany urban revitalization as tangible evidence of the ways resilience building can contribute to increased oppression (Garcia-Lamarca, et al., 2019, p. 5; Immergluck, & Balan, 2018).

While there is a consensus of a general, broad definition of urban resilience to be the ability of a city or urban system to withstand a wide array of shocks and stresses, much of the conceptual and practical understanding of urban resilience is disagreed upon (Leichenko, 2011). There are several major tensions within the broader resilience literature including equilibrium conceptualization, mechanisms of system change, the role of adaptation and adaptability, timescale of action, and the normative nature of the term (Meerow, et al., 2016). As academics and policymakers have tried to come to terms with the varied definitions of urban resilience, some of these tensions have been incorporated. For example, Meerow, Newell, & Stults proposes the following definition:

> Urban resilience refers to the ability of an urban system – and all of its constituent socio-ecological and socio-technical networks across temporal and spatial scales – to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity (2016, p. 39).

In practice, urban resilience faces a tension between specified and general resilience (Meerow, et al., 2016, p. 44). This is a contribution from the social-ecological systems (SES) discipline, highlighting how it is important to balance building resilience in particular ways for specific threats with building general resilience to unforeseen and unspecified disturbances (Miller, et al., 2010, p. 11). In the policymaking setting, this is a crucial consideration, as efforts to build resilience for one specified threat could exacerbate vulnerabilities to other threats. This

distinction between types of resilience is also described as a distinction between short-term adaptation and long-term adaptability (Meerow, et al., 2016, p. 44). In this context, the literature also stresses the importance of using generic adaptability, or general resilience, to increase flexibility in urban systems (Ahern, 2011). By incorporating notions of the analytical framework of adaptive governance, some scholars promote building system flexibility to build resilience to uncertainty (Folke, 2006). Focusing on flexibility, according to SES resilience literature, is particularly important in building urban resilience because the interconnected nature of modern cities threatens that adaptive capacity by the simple characteristic of hyper coherence and integration (Meerow & Newell, 2019, p. 312).

A growing division in the literature is an emerging debate about whether resilience is always a positive concept (Cote, & Nightingale, 2011). The systems framework that provides a foundation for urban resilience inherently emphasizes system-level function that requires balance and tradeoffs. Without close attention to the political and social nature of the systems, this approach cannot effectively evaluate distributive issues and therefore likely perpetuate the institutions that often create disproportionate vulnerabilities (Bonds, 2018, p. 3; Meerow, et al., 2016, p. 795). It should be noted that the distribution of benefits and burdens in resilience-building inherently leads to winners and losers. Many authors argue, however, that the resilience framework fails to include considerations for how those benefits and risks are distributed (Friend, & Moench, 2013, p. 99). When a systems approach views the greater public good as the function of the system overall, it is thus endorsing a type of resilience that will leave parts of the community behind, viewed as a trade-off or outlier in a utilitarian framework (Friend, & Moench, 2013, p. 102). In this way, resilience literature and practice are unable to capture

normative social practices such as justice and equity (Fitzgibbons & Mitchell, 2019, p. 649). This leads many scholars to ask, 'Resilient for who?" and "against what threats" and "at what, or whose cost? (Meerow et al., 2016).

We see the parts of this debate reflected in the extent to which the definition and implementation of urban resilience incorporate change, as opposed to resistance or recovery (Meerow, Newell, & Stults, 2016). This is often framed as a division regarding "bouncing back" or "bouncing forward," (Shaw, & Maythorne, pg. 28). Because resilience is often considered the ability to return to a "normal" or stable state following a disturbance, some scholars question *which* stakeholders will truly benefit from resilience-based actions if they retain systematic inequality (Friend, & Moench, 2013). Additionally, with an emphasis on withstanding a disaster or "bouncing back," traditional conceptions of resilience become inherently conservative and based on neoliberal reforms that puts the onus on individual communities to withstand shocks and stressors without systemic changes to improve their capacity to do so or a reduction of their unequal risk or exposure to climate threats (Davoudi et al., 2012). When resilience is put in the context of social systems and public policy, it brings with it the connotations of enduring adversity, withstanding crisis with self-reliance, and common notions of bootstrap theory instead of addressing structural factors that disproportionately distribute adversity, vulnerability, and risk or adequately addressing issues of power, justice and equity (Friend, & Moench, 2013, p. 102).

Additionally, the systems-framework of resilience promotes the ability to maintain core functions during times of disruption, however, determining what functions are core is inherently a political decision impacted by systems of power and social structures, but will have implications for groups of the community differently, particularly in terms of access, risk, and

impact mitigation (Friend, & Moench, 2013, p. 102). With those considerations in mind, many authors criticize contemporary urban resilience discourse for not incorporating issues of justice, equity, and power adequately (Vale, 2014; Fitzgibbons, & Mitchell, 2019; Meerow, & Newell, 2019).

Another facet of this debate is the fact that promoting resilience can impede the progress towards equitable distribution of risk and vulnerability in a transformative fashion. This sentiment has been expressed by communities that have faced disasters and been subsequently praised for their ability to withstand the disruption; in response to the framing of Hurricane Katrina and the BP Oil spill, Tracie Washington of the Louisiana Justice Institute rejected this normative description of "resilient," claiming it provided justification for neglect and uneven vulnerability that requires some communities to be more resilient than other to survive (Kaika, 2017, p. 95). In this light, some view the focus on urban resilience as a distraction from the focus on identifying "actors and processes that produce the need to build resilience in the first place" (p. 96).

It's also been noted that this repeated coping that is often referred to as resilience is not conductive to climate change adaptation, particularly when considering the need to focus on long term escalation of the frequency and intensity of climate change hazards (McEnvoy, et al., 2013, p. 287). In essence, this lens on resilience highlights how many conditions of a system can be resilient while still highly undesirable, such as income and wealth gaps, dictatorships, and carbon-focused energy sectors (Gunderson & Holling, 2002; Wu & Wu, 2013).

In light of these critiques, a growing number of cities are incorporating a social equity lens into their climate adaptation and urban resilience plans and highlighting the need to provide

marginalized communities with resources to build adaptability and capacity, furthering a social justice component (Meerow, Pajouhesh, & Miller, 2019, p. 793; Meerow & Newell, 2019, p. 313). Meerow and Newell (2019) have used the critical research around resilience and environmental justice to formulate a framework for practitioners to utilize when working towards resilience, which stresses the importance of the "5 W's": whose resilience is prioritized, against what shocks, when, where, and why (p. 310).

Gentrification

One resilient condition of cities, like income disparities and wealth gaps, is the phenomenon of gentrification. Gentrification occurs when a low-value housing area with historical disinvestment becomes more desirable to higher-income households or investors, prompting housing market changes that cause out-migration of longstanding residents (Bates, 2013, p. 9). Gentrification and displacement due to resiliency projects, or the market changes that occur as a result of these projects, is a prime example of the "winners and losers" criticism of urban resilience. Characteristics of gentrification are housing market changes, economic status changes, and demographic changes that alter the character of a neighborhood (2013, p. 9). Gentrification does not always lead to neighborhood change, but this displacement is possible due to rising rents, loss of subsidized housing units, and loss of community (2013, p. 11).

The impact of environmental or green gentrification can be seen in iconic park systems like New York City's High Line and Atlanta's BeltLine, however, research shows that smaller parks and green spaces can also create similar neighborhood appreciation (Immergluck, & Balan, 2018; Rigolon & Németh, 2020). Like greenways, urban sustainability planning that includes green beautification tactics can revalorize previously underinvested neighborhoods, contributing

to gentrification and even being viewed by the long-standing residents as "green locally unwanted land uses (green LULUs)" (Shokry, Connolly, & Anguelovski, 2019, p. 2; Anguelovski, et al., 2016). In this way, the "depoliticized promotion" of resilience interventions as inherently beneficial for the communities that receive them could be overlooking entrenched and ongoing social inequities that lead to uneven outcomes (Shokry, Connolly, & Anguelovski, 2019). This subsection of environmental gentrification, referred to as green resilience gentrification, is an emerging literature.

Green Infrastructure and Flood Risk Reduction

Origins of green infrastructure can be found at the beginning of modern environmentalism, conservation, and landscape architecture (Pankhurst, 2010). Green infrastructure as a concept has been linked to planning approaches such as the Garden Cities movement, landscape ecology, and holistic urban smart growth plans (Mell, 2017). Often referred to as "low impact development (LID)," "best management practices," "greenway planning" or "green space management," the terminology did not reach a consensus around green infrastructure until the early 2000s (Hoover, & Hopton, 2019, p. 1141; McDonald, et al., 2005).

Definitions of green infrastructure and frameworks for implementing it have not reached an academic or practical consensus. Research by Sussams, Sheate, and Eales (2015) looked at 20 different definitions from stakeholders, highlighting differences and similarities in scale, benefits, and approach within each definition. Three highly cited and utilized definitions have emerged as the most consistent, the Benedict and McMahon definition (2006), the Natural England definition (2009), and the European Commission definition (2013) (Mell, 2017).

Agreement among the conceptual understanding and defining of green infrastructure provides the following definition: 'a strategically planned network of natural and semi-natural areas with environmental features designed to deliver a wide range of ecosystem services' (Sussams, Sheate, & Eales, 2015).

The evolution of green infrastructure has occurred in three eras, the exploration (1998-2007), the expansion (2005-2010), and the consolidation (2010 – current) (Mell, 2017). As definitions and frameworks have varied, the versatility of the elements of green infrastructure allows it to be malleable to different contexts and locations. Multifunctionality has become a core element of green infrastructure planning, where multiple ecological, social, and economic functions are combined in an aim to use space more efficiently (Hansen & Pauleit, 2014; Ahern, 2011; Kambites & Owen, 2006).

The multifunctionality of green infrastructure is exemplified in its use as a climate adaptation tool. Internationally, green infrastructure has been identified as an adaptation option for coastal communities as well as urban centers because it can improve stormwater management, reduce flood risk, moderate the heat-island effect, and build a buffer for storm surge (Nobel, et al., 2015, p. 846 – 848; Novotny, Ahern, & Brown, 2010). The European Environment Agency identified three main climate change adaptation benefits of green infrastructure: mitigating the urban heat island effect, managing flood risk, and building ecosystem resilience but scholars also note the contribution green infrastructure offers concerning runoff and water quality improvements (Sussams, Sheate, & Eales, 2015, p. 185; Gill, et al., 2007). Green infrastructure is also seen as multifunctional due to ancillary benefits such as ecological conservation, recreation space, and aesthetic enhancement (Lennon, 2015).

Green infrastructure is often touted as beneficial to the local economy by providing green job creation and cost-effective urban planning (Immergluck, & Balan, 2018; Ahern, 2007). However, between the primary functions of providing ecosystem services and building climate resilience, as well as the ancillary benefits, some research indicates that green infrastructure development can cause increases in real estate value that leads to displacement of marginalized populations to areas that offer less attractive features (Lovell & Taylor, 2013). Research over the last decade has exposed how urban sustainability, green beautification, and efforts to revitalize communities with new green amenities can contribute to gentrification (Shokry, Connolly, & Anguelovski, 2019, p. 2; Gould & Lewis, 2018; Anguelovski, 2016).

The phenomenon of environmental gentrification, also known as green gentrification, occurs most often in response to investments such as bike paths, urban parks, and sustainable urban planning (Anguelovski, et al., 2016; Lubitow, et al., 2016; Gould & Lewis, 2017; Rigolon & Nemeth, 2020).

However, as resilience planning gains traction in urban policy, further research has delved into how equitable resilience investments have been. Recent research based in Philadelphia reviewed green resilience infrastructure siting and patterns of gentrification, revealing that the most socio-ecologically vulnerable residents were not benefiting from the new infrastructure, and areas with more investments became wealthier, whiter, and better educated (Shokry, Connolly, & Anguelovski, 2019, p. 12). Some researchers have identified such strong relationships between resilience investments and housing cost increases that they warn of a dual process of resilience gentrification where urban greening and climate adaptation contribute to the notion that resilience is equated to wealth, creating a new urban elite and further disadvantaging

the already vulnerable populations (Gould & Lewis, 2018). There is some research establishing a relationship between low-impact development on property values, concluding that values increase with the implementation of LID (Hoover, & Hopton, 2019; Mazzotta, et al., 2014). When the application of green spaces is done uncritically, these projects can evolve into socially exclusive amenities perpetuating socio-spatial inequities (Peasall, & Anguelovski, 2016). Sarah Dooling (2009) used the term "ecological gentrification" to describe how the implementation of an environmental planning agenda that uses public green spaces can lead to the exclusion of the already economically and socially vulnerable while espousing an environmental ethic (p. 630; Anguelovski, et al., 2019, p. 3). Displacement and precarious housing status become particularly problematic when the original goal of the green infrastructure was to build community resilience to climate stressors such as flooding and urban heat (Wolch, et. al., 2014). The socio-economic impacts of urban greening that specifically targets lower-income communities have resulted in some communities perceiving these interventions as Green Locally Unwanted Land Uses (or GreenLULUs) (Anguelovski, 2016).

As research has better understood the connection between improvements to environmental quality and gentrification, some scholars have proposed concepts to mitigate the disbenefits of urban greening, such as "just green enough" (JGE) from Curran and Hamilton (2012). After reviewing brownfield redevelopment and the green gentrification that followed it, Curran and Hamilton propose the need to include 'industrial uses and the working class' in greening initiatives instead of only providing space for 'parks, cafes, and a Riverwalk' (2012, p. 1028). The "just green enough" strategy aims greening and clean-up efforts at the existing working-class population without encouraging new development (Curran & Hamilton, 2012, p.

1028). The goal is to create clean up initiatives that are "just green enough to improve the health and quality of life of existing residents," without attracting new residents that provide incentives for upscale, "sustainable" housing and, therefore, gentrification (Curran & Hamilton, 2012, p. 1028). Other researchers have studied and promoted complementing green initiatives with housing policies that protect existing residents from housing cost shifts (Wolch, et al., 2014). Finally, rent stabilization programs or homeownership incentives have been suggested as a way to protect residents while encouraging further social investment in improving neighborhoods (Wolch, et al., 2014, p. 241).

While both green amenities and resilience investments have been identified as catalysts for gentrification, there is not an established empirical understanding of in which context or what types of green infrastructure projects contribute most to the process of gentrification. Furthermore, there is not research connecting the efforts of incorporating equity and justice into resilience planning and the outcomes of green gentrification. Addressing these gaps in the literature could provide academics and practitioners more guidance on policy construction as they approach urban planning intending to balance affordability, climate resilience, and equity.

Chapter Two: Theoretical Framework

Environmental Justice

Environmental justice was originally born out of the civil rights movements and in congruence with antitoxic and waste campaigns and environmentalism (Mascarenhas, 2015, p. 165). As awareness of environmental inequalities among particular social groups grew and protests regarding landfills in majority African American communities, such as Warren County, North Carolina, garnered attention, federal action in the form of a Presidential E.O. established the importance of environmental justice (2015, p. 166). Gaining further momentum from additional publications highlighting unequal health outcomes and risks due to unequal exposure to environmental hazards as well as the activism of people of color throughout the 1980s and 90s, the environmental justice paradigm was adopted through the "Principles of Environmental Justice" at the 1991 People of Color Environmental Leadership Summit (Taylor, 2002, p. 39). The environmental justice movement also encapsulated movements for better occupational health and safety, indigenous land rights, public health, and economic and social justice (Faber & McCarthy, 2003). Additionally, the environmental justice movement challenged traditional characterizations of "environment," moving away from conventions of 'wilderness' and instead focusing on where people "live, work, and play" and engaging indigenous conceptions of the relationship between human beings and nonhuman nature (Schlosberg, 2004, p. 360). Scholarship of environmental justice has continued to expand to include a growing number of topics and fields including transportation, urban planning, disaster management and response, food justice, and more (2004, p. 361).

As the impacts of climate change have become better understood, so has the distribution of burdens associated with climate change, prompting the growth of climate justice, a subcategory of environmental justice that acknowledges the hardships associated with climate change and the ways it currently and will increasingly affect already vulnerable populations more intensely (2014, p. 361). Across race, ethnicity, and disaster literature, studies indicate increased risk and vulnerability to disasters for communities of color (Fothergill et al., 1999). In light of the growing criticisms of the urban resilience paradigm, scholars have also deployed concepts of environmental and climate justice to evaluate how well resilience strategies advance justice in planning processes and outcomes with particular attention to distributional, recognitional, and procedural justice (Fitzgibbons & Mitchell, 2019, p. 649).

Distributional Equity

A traditional conceptualization of justice has been primarily concerning the distribution of goods and freedoms, as theorized by John Rawls, where a just outcome would involve fair allocation of material goods for all members of society (1971, p. 9). This may involve social goods allocated explicitly to disadvantaged populations to improve welfare (Schlosberg, 2004). In the context of resilience to climate change, several studies have highlighted the inequities of land use planning in the forms of "acts of commission," where negative consequences of resilience-building are primarily impacting disadvantaged communities, and "acts of omission," where already oppressed groups are excluded from the benefits of resilience-building (Anguelovski, et al. 2016; Meerow, et al., 2019). This has been demonstrated in the form of disproportionate displacement of communities of color, unequal distribution of flood mitigation

efforts, and outcomes that further exacerbate the unequal burden of climate change (Bates, 2013; Tretter, & Adams, 2012, p. 199; Liévanos, & Horne, 2017, p. 203).

More recently, distributional justice also encapsulates how risks and vulnerabilities are distributed. Increasingly, research shows that risks and vulnerabilities to climate risks are disproportionately distributed among city residents based on socioeconomic and racial factors (Cutter, et al., 2003; Fahy, et al., 2019; Baker, et al., 2019).

Recognitional Equity

It is also important to acknowledge that many distributional inequities stem from inequities in social, political, and economic recognition (Schlosberg, 2004). Recognitional equity can look like the acknowledgment of sacredness of Mother Earth as a concern for Indigenous peoples, noting the context of historical disempowerment, or including strategies in the predominant and/or minority languages (Schlosber, 2014, p. 366; Meerow, et al., 2019, p. 979; Fitzgibbons & Mitchell, 2019). The interconnectedness of recognitional justice with distributive justice is undeniable, therefore, it is crucial that resilience planning acknowledges different intersecting identities, recognizes the historical injustices and vulnerabilities that accompany those identities, and fosters respect for different groups to promote recognitional equity and support distributive equity (Meerow, et al., 2019, p. 797).

Procedural Equity

Both distributional and recognitional equity depend on a fair and equitable institutional decision-making process known as procedural equity (Schlosberg, 2004). In the context of resilience planning, this requires public, accessible, and equitable participation in the planning process, as well as intentional outreach, to engage at-risk or marginalized groups (Meerow, 2019,

p. 789). Although the importance of an inclusive participatory process is highlighted in several studies, climate adaptation planning processes often fail to have meaningful participation from underrepresented groups (Harris, Chu, & Ziervogel, 2017; Anguelovski, et al., 2016). Likewise, urban planning models rarely acknowledge the importance of democracy as a model for empowering all views as decisions about the distribution of urban amenities are made (Connolly, 2019, p. 67).

Resilience Justice Framework

In many ways, the urban resilience discourse has created a framework to be applied to urban planning and climate adaptation efforts. As that framework has been propagated throughout cities, scholars have identified gaps and weak points. From the criticism that resilience concepts do not adequately incorporate social equity, a framework of social equity in resilience planning has been established and utilized to create rubrics, evaluation criteria, and goals (Meerow, Pajouhesh, & Miller, 2019, p. 796; Fitzgibbons, & Mitchell, 2019, p. 649). This framework is three-pronged and supplements John Rawls' (1971) well-cited definition of justice as "a standard whereby distributional aspects of the basic structure of society are to be assessed," with recognitional and procedural justice, based on environmental justice literature (Meerow, Pajouhesh, & Miller, 2019, p. 796; Schlosberg, 2004; Bulkeley, Edwards, & Fuller, 2014). The original authors of this framework, Meerow, Pajouhesh, & Miller, (2019), believe that all three types of justice are crucial components to how communities build resilience. The adoption of this framework has led to the creation of criteria and planning goals for practitioners and evaluation rubrics and additional theoretical frameworks for academics (Fitzgibbons, & Mitchell, 2019; Choi, Park, & Rigolon, 2020, p. 2).

Significant to this research, Fitzgibbons and Mitchell (2019) established an evaluation rubric from Meerow, Pajouhesh, and Miller's work, transforming each branch of justice into a section of goals and criteria against which they could grade urban resilience plans. This research highlighted the wide variation of equity considerations among cities that adopted resilience plans as part of the Rockefeller 100 Resilient Cities Program (Fitzgibbons, & Mitchell, 2019, p. 653).

Just City Model

A final theoretical foundation for the qualitative component of this research is the Just City theoretical framework, which was born out of the recognition that there is a relationship between urban greening and gentrification and that the Smart Sustainable Resilient City orthodox "supports and conceals this relationship" (Connolly, 2019, p. 66). In response to this recognized relationship, Fainstein (2010) constructs the Just City framework to provide a criterion against which greening, and urban planning in general, should be judged (Connolly, 2019, p. 67). Fainstein's conceptualization of "the just city" requires the incorporation of three main principles: democracy, diversity, and equity (2010). Fainstein does not claim that this framework constitutes a "good city" but instead asserts that justice should influence all public decisions (Fainstein, 2010, p. 3).

Furthermore, this theoretical framework highlights the tensions between democracy, equity, and diversity in planning, emphasizing the gaps in deliberative democracy and the communicative model of planning that fail to recognize power dynamics and structural conflicts of interest that contribute to inequitable outcomes (Fainstein, 2010, p. 28-48). Importantly, this critique of traditional planning schemes provides insight into the Justice and Equity rubric used in evaluating resilience strategies. One notable contribution is the critique that traditional planning schemes aiming to increase the focus on justice since the 1960s have relied too heavily on democracy and participatory processes to rectify the injustices and inequities in the community, without properly accounting for 'street-level bureaucrats' and affluent citizens dominating deliberations in ways that preserve the existing inequities and further benefit the already privileged residents (Fainstein, 2010, p. 64-66).

Finally, Fainstein's vision for a just city provides some guidelines for recommendations within this research. Outlining principles for planning and urban policy that align with her focus on equity, diversity, and democracy, Fainstein promotes affordable housing policies, incremental growth, inclusive zoning, participatory democracy with targeted deliberations, and advocacy on behalf and in consultation with long-term residents (2010, p. 172-175). Components of the justice and equity rubric for evaluating resilience strategies as well as recommendations in the discussion of this research's findings borrow from these ideas.

Gentrification as a framework

In addition to frameworks of Resilience Justice and Just City planning, this research, particularly the quantitative component, relies on conceptualizations and frameworks to understand gentrification.

There are several validated methods of conceptualizing and quantifying gentrification and different variable selection has a large impact on outcomes of identifying neighborhoods undergoing gentrification (Easton, et al., 2020, p. 288). Operationalizing gentrification is difficult because it needs to capture both market trends and population changes, which may be difficult to measure (Bates, 2013, p. 28). The Freeman Method is considered a reliable indicator of gentrification because it utilizes several markers to signal neighborhood change, including median income, housing age, urbanity, and education attainment, which are all rooted in a strong conceptual framework (Mujahid, et. al, 2019). The use of a multi-dimensional operationalization of gentrification has been more common in recent research as analysts recognize the complex range of relationships between social and economic neighborhood change (Easton et al, 2020, p. 288). The most common combination of variables includes the change of income, education

level, and home values (Maciag, 2015; Desmond & Gershenson, 2017). This research is grounded in framing gentrification as measured by changes in medium income, portion of adult population with a bachelor's degree, and the medium housing value.

Chapter Three: Case Studies

I selected three cities to conduct a mixed-methods comparative case study: Washington, D.C., Houston, Texas, and Portland, Oregon. These cities were chosen for a variety of factors. First, each city faces a threat of stormwater flooding due to climate change. Each city has a unique context in which this flooding is problematic, which will be discussed further in subsequent sections. In the same vein, each city has drafted and enrolled a plan to address climate threats to their city. While Washington D.C. and Houston, Texas participated in the Rockefeller 100 Resilient Cities program (100 RC), Portland, Oregon has worked on Climate Action Plans every 5 years since 1993 (Turner et al., 2020; Bowser & Young, 2019; Anderson, et al., 2015). Additionally, each city has a different history of green infrastructure use, with Portland and Washington D.C. having well-established programs and initiatives to shift away from gray infrastructure and towards green infrastructure, and Houston having a less mature and centralized strategy. Finally, each city has a different approach to urban planning and zoning with some approaches focusing on limiting urban sprawl and others leaving more up to market mechanisms. Despite this variety in regulation, each city has deep roots in segregation, environmental racism, and inequitable urban planning. Each of these factors adds to the richness of each case study and contributes to a greater understanding of how green infrastructure relates to housing affordability and equity.

Rockefeller 100 Resilient Cities program (100 RC)

The 100 Resilient Cities program was created by the Rockefeller Foundation in 2013 and funded by the Rockefeller Philanthropy Advisors (RPA) until 2019 (*100 Resilient Cities* -

Climate Initiatives Platform, n.d.).[1] The goal of 100RC was to help cities around the world become more resilient to physical, social and economic challenges that are a growing part of the 21st century, incorporating a view of resilience that includes short-term shocks and long-term and sustaining stresses that are both natural and man-made. The program provided participating cities with resource along four main pathways: guidance in creating the Chief Resource Officer position, support in developing a resilience strategy, connection to partnerships in private, public, and NGO sectors, and membership in a global network of 'resilient cities' (Bowser & Young, 2019).

Each resilience strategy is created with the unique threats, vulnerabilities, strengths, and existing conditions of each city; however, The Rockefeller Foundation provided a framework for development of the resilience strategies. 100RC defines urban resilience as "the capacity of individuals, communities, institutions, businesses within a city to survive, adapt and grow no matter what kinds of chronic stresses and acute shocks they experience" (Turner, et al., 2020). Much of the information about identified threats and existing programs outlined later in this chapter come from the individual resilience strategies.

[1] Since the closure of 100RC, much of the work has been taken on by two new organizations, Resilient Cities Catalyst and the Global Resilient Cities Network.

Washington, D.C.

Background

Washington, DC provides a unique case study because it is the capital of the United States of America and fulfills the functions of a city, county, and state while being limited in rights, authority, and governance power. Due to the DC Home Rule Act of 1973, DC has an elected Mayor and Council, but Congress retains some critical authorities. Additionally, Washington DC has a rich and complex history of segregation on racial and economic lines, with policies such as redlining and discriminatory zoning still impacting communities today (Mitchell & Franco, 2018).

DC also provides insight because of the relationship this area has with residential growth and development. DC has a population of roughly 700,000 but is expected to increase to over a million people by 2045 (Bowser & Young, 2019). Limited by region and efforts to control urban sprawl, the housing cost of DC is projected to increase as the gap between supply and demand for housing widens. Furthermore, Washington, DC is one of the most congested regions in the country partially due to the role it has as the host of the federal government and as a regional employment hub (Bowser & Young, 2019).

Climate Threats

As a city, Washington DC faces several climate threats including warmer temperatures and heatwaves, more frequent and intense heavy rain events, rising sea levels and storm surge, extreme weather events, and flooding (Wells, 2016). Importantly, Washington, DC is a delta city with the Potomac and Anacostia rivers. Inland flooding as well as the rising level of both rivers

creates concern for the stormwater infrastructure of the city as well as the safety and livability (Bowser & Young, 2019).

Additionally, due to the connectivity of Washington, DC to the greater region, the city faces chronic stressors and is vulnerable to shocks unrelated to climate yet exacerbated by climate change, such as terrorism, federal government shutdowns, and civil unrest. The connection between resource competition and conflict, as well as natural disasters and diplomatic deterioration, is well-established, with climate change often referred to as a "threat multiplier" (Martín, n.d.). As climate change impacts are felt more intensely by the United States, the political discourse around mitigation efforts and international diplomacy will likely become more volatile, adding an additional layer of vulnerability to political instability. As the capital of the United State, Washington, DC will feel this threat acutely.

Green Infrastructure Program

Washington DC has a long history of green infrastructure utilization, with some programs dating back to the mid-1970s (District of Columbia Department of Energy and Environment, 2020). Since 2007, green infrastructure, or often referred to as Best Management Practices (BPMs) has largely been used to mitigate pollution in the Potomac and Anacostia rivers. Notably, DC is served in part by a combined sewage system (CSS) and in part by a municipal separated sewer system (MS4) and has not met water quality standards set by the Clean Water Act since 2002, leading to a 2005 Consent Decree that, among other bindings, led to investments in green infrastructure programs (Lim, 2018). To date, most of the green infrastructure programs are run by or in congruence with the Department of Energy and Environment (DOEE), formerly named the District Department of Environment (Lim, 2018). In addition to voluntary programs

such as the RiverSmart Program, DOEE, and DC Water have implemented two “required” green infrastructure construction policies including ordinances that require landscape and vegetation quality standards to be met with zoning rules and new construction (Lim, 2018).

Within the Resilient DC plan, DC highlights green infrastructure as a tool to mitigate the impacts of the urban heat index. The plan also identified green infrastructure as a priority for investment with the proposed “DC Green Bank,” an initiative aimed at funding energy-efficient investments for property owners.

Houston, Texas

Background

Houston, Texas is a strong case study for this research because the city faces major climate threats related to flooding, has a history of segregation and spatial environmental inequality, and has recently implemented incentives for green infrastructure investments, indicating a stronger focus on this tool as a resilience-building mechanism (Turner, et al., 2020; Smiley, 2020, p. 2; Whalen, 2020). Houston also provides a strong comparison to Portland, Oregon because of its unique system of "non-zoning" (Berry, 2001). Houstonians have voted by referenda multiple times to reject proposed zoning and instead, embrace a private system of land use control (Buitelaar, 2009).

As the only major city in the United States without a zoning plan, Houston provides a unique case study for gentrification as well as equity considerations. Zoning has been identified as a crucial exclusionary device in suburban and urban areas, leading to both economic and racial segregation (Berry, 2001). However, many of those outcomes have persisted in un-zoned Houston as an outcome of the private market mechanisms at play in the city's development (Berry, 2001). It is undeniable that the marketplace provides sufficient economic incentives for segregation of uses and users, creating patterns of development and residential demographics that reflect those of zoned cities (Siegan, 1972; Berry, 2001). Historically, the municipal government in Houston has set policies favorable to private-sector growth and not prioritized community development or input (King & Lowe, 2018, p. 1163). This pattern of disenfranchisement runs parallel to the patterns of exclusion of communities of color in governance and the diluting of cultural centers such as Second Ward's Chinatown and

Freedmen's Town, the original epicenter of Houston's African American community (King & Lowe, 2018; Ehrenhalt, 2012; Knapp & Vojnovic, 2013).

Climate Threats

Houston, Texas sits in Southeast Texas near Galveston Bay and the Gulf of Mexico. These large bodies of water have been crucial to the growth and prosperity of Houston but have also opened it up to climate threats including hurricanes, sea-level rise, storm surge, and flooding. In 2017, Hurricane Harvey dumped one trillion gallons of rain on Houston and became one of the most damaging natural disasters in U.S. history and just one of the six major flooding events that earned federal disaster declarations in five years (Turner, et al., 2020).

Additionally, Houston has a long history of climate and environmental justice issues. The city has been the setting for several studies connecting racial, ethnic, and socioeconomic inequalities in the distribution of poor air quality, toxic waste facilities, and even natural disaster impacts (Ma & Smith, 2020; Collins, et al., 2019; Chakraborty, 2019, p. 246). In efforts to mitigate flood risk, the city has controversially proposed using eminent domain to convert the area of 400 low-income households to green space (Shi, 2020).

Green Infrastructure Program

Houston's use of green infrastructure for stormwater management does not have as long of a history as Portland, Oregon, or Washington DC. Throughout the Resilient Houston plan, there are references to future investments in green infrastructure programs and low-impact development projects. Some agencies and associations such as the Bayou Preservation Association have worked with low-impact development demonstrations to exemplify the benefits of green infrastructure to stormwater management and water quality control (NPS Program). The

most significant program for green infrastructure, referred to as low impact development (LID) projects, is the “Designing for Impact” program from the Houston-Galveston Area Council (H-GAC), which provided the data for this research. In 2020, the City of Houston and the Houston Endowment used a one-year study on green stormwater infrastructure to move forward with incentive programs such as a tax abatement program to encourage the use of green stormwater infrastructure in private land development (Whalen, 2020). This indicates the city’s increasing commitment to achieving a more robust green infrastructure program.

Portland, Oregon

Background

The growing urbanization of Portland has brought forward issues of gentrification and social segregation (Fahy, et al., 2019, p. 2). During the last few decades, the North and Northeast regions of Portland have experienced increased investments in the form of public revitalization projects as well as private investments, leading to increases in housing prices and subsequent changes in demographic and economic composition (Bates, 2013, p. 4). As residential prices increase in response to the revitalization of these neighborhoods, low-income residents have been involuntarily pushed to the east side of the city (Bates, 2013; Williams-Rajee & Evans, 2016, p. 5). This process of gentrification has not only created a shift in demographic and socioeconomic profiles of the neighborhoods, but it has also created a strong force of segregation and disparities of resources, as East Portland has far less transit connectivity, sidewalks, and other crucial infrastructure for livability (Williams-Rajee & Evans, 2016, p. 5). Displacement in the north and northeast region of the city is not new; throughout the mid-1900s, during the urban renewal era resulting from the Housing Act of 1949, revitalization efforts and freeway construction displaced thousands of residents in the Albina neighborhood (Wollner et al., 2001). In fact, by some estimates, the Interstate Corridor Urban Renewal Area displaced more than 10,000 Black residents from the Albina area (Hughes, 2019). Since the 1920s, land-use practices, particularly residential zoning, of Portland have contributed to the patterns of increased vulnerability to displacement aligning with the racially segregated boundaries (Hughes, 2019, p. 19-20).

Portland City planners and leaders are not unaware of the issues of racial and economic segregation or the issue of uneven vulnerability to gentrification and displacement. In 2005, the city launched VisionPDX, an effort to engage communities of underrepresented groups in city planning (Hughes, 2019). Additionally, the city has attempted to address gentrification and urban renewal with a strategic response in the Portland Plan since 2009, as well as in the *2015 Climate Action Plan* (Hughes, 2019, p. 17; Bates, 2013; Williams-Rajee & Evans, 2016). While the effectiveness of the strategies proposed in the Portland Plan is beyond the scope of this study, the action taken at the city planning level is an important backdrop to this research.

Similarly, it is important to understand the unique land use and zoning policies in place in Portland. In addition to the impact of Urban Renewal Areas and Community Plans, Portland has the added factor of an urban growth boundary, implemented in 1995 as part of the 2040 Growth Concept as a way for the city to handle urban sprawl while capturing the benefits of population growth and economic booms (Gibson, 2007). However, this is often referenced as a major contributing factor to the rapid gentrification and racial transitions of neighborhoods in prime central city land in the 1990s (Hughes, 2019; Gibson, 2007).

Climate Threats

The City of Portland is located in Northern Oregon near the confluence of two major rivers, the Columbia and the Willamette. The Willamette has a Superfund site and is the habitat for multiple endangered species, exemplifying the environmental challenges in the area (Netusil, et al., 2014, p. 15). Additionally, Portland and Multnomah County have identified five major climate risks falling into two categories: hotter, drier summers, and warmer winters with more extreme rain events (Anderson, et al., 2015, p. 24). Throughout climate mitigation and adaptation

plans for Portland and Multnomah County, as well as for Oregon as a whole, the primary risks are increased temperatures, drought, wildfire, flooding, and landslides (Anderson, et. al., 2015, p. 24). Because this region of Oregon experiences a wet season from December to March and recent in-fill development has increased the urbanization of the area, Portland has experienced frequent nuisance flooding (Fahy, et al., 2019, p. 2). In addition to urban flooding and stormwater runoff concerns, Portland struggles with even moderate rainfall triggering combined sewer overflows (CSO), resulting in untreated sewage entering the Willamette and Columbia Rivers (Netusil, et al., 2014, p. 15). A combined sewer system (CSS) is a wastewater collection system that transports sanitary waste with stormwater in a shared system of pipes and drainage networks (National Research Council, 2009; Hoover, & Hopton, 2019, p. 1139). The city has invested consistently over the last 20 years in physical infrastructure improvements to decrease the risk and intensity of COS, funded by rate increases to sewer/water bills (Netusil, et al., 2014, p. 15).

While Portland, Oregon did not participate in the 100 RC program, the city has drafted and implemented the *Climate Action Plan* every 5 years, since 1993 (Anderson, et. al, 2015, p. 137). The most recent plan, and the document used in this analysis, is the *2015 Climate Action Plan*. This plan serves as a sufficient comparison to the resilience plans of Washington D.C. and Houston because it identifies goals, objectives, and actions, that aim to not only mitigate climate change but also adapt or as put in the plan, prepare for its impacts (p. 106). To supplement this plan and make it more comparable to the resilience plans of Washington DC and Houston, TX, I also analyze the Climate Action Through Equity document, which summarizes the actions taken during the creation of the *2015 Climate Action Plan.* In this way, Portland is a strong case study

for equity considerations, as the 2015 plan is the first to intentionally incorporate equity and the supplemental document provides a thorough description of how this was done. Throughout the plan, green infrastructure is highlighted as a tool to mitigate the impacts of threats like the urban heat index and urban flooding, helping the city to prepare for climate change and build resilience (Anderson, et. al, 2015, p. 27).

Green Infrastructure Program

Portland, Oregon has been considered a pioneer in sustainability and urban greening. Water infrastructure programs like the downspout disconnection program have been used as municipal success stories for their ability to limit the amount of rain entering the combined sewer system and assisting with groundwater recharge (Dunn, 2008, p. 53). Notably, Portland has been implementing green infrastructure since the 1990s to reduce the occurrence of CSO (McPhillips & Matsler, 2018).

The flagship program of green infrastructure investments in the City of Portland is the Green Streets Program, initiated by the Grey to Green plan in 2008 (Netusil, et al., 2014, p. 15). Green streets, a term also used by the Environmental Protection Agency, refer to low-impact development techniques that use "vegetated facilities to manage stormwater runoff at its source" (What is a Green Street?, 2019). In Portland's Climate Action Plan, the green streets program was identified as one way to increase the resilience of natural systems to respond to rising temperatures, droughts, and shifts in regional precipitation (Anderson, et. al, 2015, p. 114).

Chapter Four: Qualitative Analysis

This research uses a mixed methodology approach to answering questions about the extent to which cities incorporated equity into resilience planning and the impact green infrastructure as a climate resilience tool has on gentrification. First, I use content analysis to evaluate the justice and equity considerations of resilience planning in each city.

Data and Methodology

As part of the analysis of resilience planning, this research looks closely at resilience plans in each city using content analysis and a justice and equity rubric.

Justice and Equity Rubric

Based on work from Fitzgibbons & Mitchell (2019), as well as Meerow et al. (2019), I developed a justice and equity rubric to evaluate resilience plans (Appendix A). This rubric is based largely on Fitzgibbons & Mitchell's rubric used in "Just urban futures? Exploring equity in '100 Resilient Cities'" (2019). I have made adjustments to incorporate a focus on gentrification, housing security, and the use of green infrastructure. The justice and equity rubric employs a three-pronged conceptualization of justice that integrates recognitional justice, distributive justice, and procedural justice (Fitzgibbons & Mitchell, 2019). Within the three dimensions of justice, the rubric highlights other components of equity and justice including acts of omission, acts of commission, vulnerability, transparency and participation, and monitoring and evaluating. These components are exemplifications of how recognitional, distributive, and procedural justice manifests in urban planning, and resilience planning in particular.

Data and Content Analysis

Data for this analysis was collected directly from each city's website. Washington DC and Houston, Texas were part of the 100 Resilient Cities program and created plans through the Rockefeller Foundation. Portland, Oregon was not part of this program but has implemented a Climate Action Plan every 5 years, since 1993 (Anderson, et. al, 2015, p. 137). To supplement this plan and make it more comparable to the resilience plans of Washington DC and Houston, TX, I also analyze the Climate Action Through Equity document, which summarizes the actions taken during the creation of the 2015 Climate Action Plan. The documents that were analyzed, as well as their source, can be seen in Table 1.

Table 1: Documents analyzed for content analysis

Name	**City**	**Citation**
Climate Action Through Equity: The integration of equity in the Portland/ Multnomah County 2015 Climate Action Plan	Portland, OR	Williams-Rajee, D., & Evans, T. (2016). Climate Action Through Equity: The integration of equity in the Portland/ Multnomah County 2015 Climate Action Plan. City of Portland, Oregon, July, 1–20. www.portlandoregon.gov/bps/cap
2015 Climate Action Plan of the City of Portland	Portland, OR	Anderson, S., Armstrong, M., Crim, M., Diesner, K., Evans, T., Fish, I., Williams-Rajee, D., & Lynch, T. (2015). 2015 Climate Action Plan City of Portland.
Resilient DC: A Strategy to Thrive in the Face of Change	Washington, D.C.	Bowser, M., & Young, R. (2019). Resilient DC: A Strategy to Thrive in the Face of Change. https://resilient.dc.gov/
Resilient Houston	Houston, TX	Turner, S., Aho, M., & Sarkozy-Banoczy, S. (2020). Resilient Houston. https://www.houstontx.gov/mayor/chief-resilience-officer.html#:~:text=Resilient Houston%2C the City's resilience,local%2C regional%2C, and partners.

Findings

Each city scored between 20.5 and 22 on the Justice and Equity rubric used to score the resilience strategies. Table 3 displays the points allocated for each criterion, subtotals for each category, and the overall score. Overall scores are not meant to be used as a comparable quantification of the focus on justice and equity, but rather as a tool to evaluate overall incorporation of these tenets and present a framework for deeper evaluation. By providing scores for each category, the rubric allows me to focus on specific components of justice and equity while still seeing the larger picture within the resilience strategy. While a score of 20.5 is not drastically different from a score of 22, each of the cumulative scores (out of 30 points) provides evidence that none of the three cities incorporated justice and equity into their resiliency strategies in a full or integrated way. Below, I elaborate on the scores for each plan and describe noteworthy findings.

Table 2: Justice and Equity Rubric scores for each city by subsection

Criteria Category	**Possible Points**	**D.C.**	**Houston**	**Portland**
Recognitional and Distributive: Act of Omission	6	2.5	5.5	5
Recognitional and Distributive: Acts of Commission	3	2.5	1.5	3
Recognitional and Distributive: Vulnerability	6	4.5	2	5
Procedural: Transparency and Participation	11	8.5	10	6
Procedural: Monitoring and Evaluating	4	2.5	3	2
Total	**30**	**20.5**	**22**	**21**

Washington D.C.

Washington D.C. scored 20.5 out of 30 points on the Justice and Equity rubric. While the plan addressed equity as it related to each established goal and vision, it failed to provide specific details that allowed for the promotion of equity over the mechanism of neoliberalism as it applies to climate resilience and other shocks and stressors in the city, such as housing affordability. This was a reoccurring theme throughout the plan, which prevented D.C. from scoring full points in any of the categories.

Recognitional and Distributive Justice

Washington D.C.'s strategy identified equity and inclusion as a component of each goal and vision for building urban resilience. However, the strategy lacked a detailed and explicit definition and understanding of vulnerability, making it difficult to establish a steadfast plan to achieve recognitional and distributive justice. For example, while the strategy acknowledges the ways municipal systems can exacerbate vulnerability, referencing past policies like redlining and current disenfranchisement, it offers limited information about how the city plans to rectify this issue.

Although the strategy does not supply a detailed definition of vulnerability, it does establish a connection between socioeconomic factors and vulnerability. In this same vein, some of the pilot initiatives and programs designed to mitigate risk and vulnerability specifically target low-income communities and communities of color. For example, the Resilient Rivers program not only attempts to address the risk of flooding in DC's riverfront communities but also identifies pilot locations that have increased risk due to exposure to climate change impacts and a higher vulnerability due to socioeconomic disparities. According to the strategy, efforts of this

program were targeted to areas along the Anacostia River such as Southwest DC and Kenilworth Park because they are most at risk of flooding and are currently experiencing significant disparities in opportunity. A key equity strength of this program is that it explicitly states displacement as a potential outcome of increased investment in riverfront communities and establishes the goal of "proactively investing in anti-displacement strategies." (p. 35). Although the strategy goes on to identify affordable housing as an objective in their inclusive growth section, most initiatives proposed are targeted towards homeowners and few apply to renters. In this way, the strategy fails to recognize how some of the benefits of the plan will not be accessible to vulnerable stakeholders in the city.

Procedural Justice

The Washington D.C. strategy outlines the process of its creation with details about the 100 Resilient Cities program, community partnerships, the agenda-setting workshops, the generation of solutions and ideas, and the feedback collected for refinement. Although the strategy states that the agenda-setting process involved the engagement of 500 individuals from government, business, nonprofits, and municipal agencies, there is no evidence that community members were involved in identifying needs and priorities. Additionally, the workgroups tasked with researching critical issues and identifying ways to build resilience were active during the summer of 2018 and required unpaid volunteer work, creating an additional barrier to engagement for some socioeconomic groups. The strongest component of collaboration with community members was during the refinement stage, which included stakeholder feedback gathered on an online platform and from open house forums held in all 8 wards. The strategy

reports data of residential engagement during this stage but does not include the demographic composition of those consulted.

Although the strategy identifies some ways municipal systems may exacerbate vulnerability, it does not acknowledge how the municipal systems may produce systemic barriers to engagement or procedural justice. This was evident in the lack of effort to reach vulnerable communities in the formation of the strategy. Likewise, there is no evidence that the strategy or the documents disseminated while soliciting feedback were provided in any language other than English. Even with some information about obtaining feedback, establishing equity indicators, and sharing best practices, the strategy does not provide a straightforward plan to dismantle procedural injustice beyond setting goals of a "more inclusive and responsive government."

Houston, Texas

Houston scored 22 points out of the 30-point rubric of Justice and Equity. The city excelled in procedural justice but lacked in areas of recognitional and distributive justice.

Recognitional and Distributive Justice

While Houston's strategy attempts to mitigate acts of omission by recognizing disparities in opportunity and the history of disinvestment along racial and socioeconomic lines, it does not adequately define vulnerability or acknowledge ways the municipal system contributes to uneven vulnerability. Even as benefits of resilience-building are directed at vulnerable groups, such as weatherization programs that are geared towards low-to-moderate-income households, the structural and historic origins of their vulnerability are never discussed. When patterns of disenfranchisement or disinvestment are acknowledged, the strategy uses a passive voice, implying the perpetrator is unknown and cannot be held accountable. This establishes a gap

between the distributive justice promoted in the strategy and true recognitional justice. Additionally, targeted benefits exist primarily in the form of reinvestments, increased educational opportunities, and dissemination of information about already existing programs. While the strategy proposes an equity metric to guide investments of green space and ensure that low-income areas have access to parks and recreational areas, there is no acknowledgment of how this investment could impact housing access and displacement, providing an opportunity for a significant act of commission in the form of gentrification.

Procedural Justice

Houston's strategy promotes procedural justice with transparency, participation, monitoring, and evaluation. The "Developing the Resilient Houston Strategy" provides ample information about stakeholder engagement, the process of participation, methods of consultation, information dissemination, and public engagement. Although the strategy was presented to the public through multiple means and in multiple languages, there is no evidence that the public was provided the opportunity to define the problems they face or engage in solution formation. There is also little data on who participated in the feedback program or how stakeholders were chosen. When confronted with the possibility of negative impacts from specific programs outlined, the strategy declares the "robust community-informed approach" established in the plan as the primary tool of mitigation. This 'approach' is kept vague and does not provide much guidance on how the community will be consulted or how the approach or its outcomes will be monitors.

The strategy is portrayed as a guiding document that is still receiving feedback but does not outline a clear framework for monitoring progress, though each goal has clearly stated

indicators of success. One significant strength of the procedure, however, is that equity is consistently established as a marker of success and one goal in the strategy is to create a program to monitor equity indicators. This program is referenced as a key way to engage community stakeholders in providing feedback and improving upon the strategy, but that process is not detailed in the document.

Portland, Oregon

Portland, Oregon scored 21 on the Justice and Equity rubric, performing best in recognitional justice, particularly with acts of commission but doing poorly overall in procedural justice.

Recognitional and Distributive Justice

Portland's plan, and the equity documents that supplemented it, devoted ample attention and care to issues of recognitional and distributive justice. This section of the rubric evaluates how well the plan acknowledges the harm that has been or could be done to vulnerable residents in the process of building climate resilience by determining if the plan considers disparities in access to benefits or disbenefits associated with resilience investments. It is important to note that this rubric cannot evaluate how well the plan, or the city mitigates these impacts once they have identified them and only provides an evaluation lens of the materials within the documents. Notedly, a plan may establish concerns and identify areas of need, establish a plan to mitigate those needs, but not follow through with the needed actions. The follow-through is beyond the scope of this study.

Portland's plan scored well in this category because it specifically identified communities that have been left out of investments and city amenities in the past and could be further

disenfranchised by the inaccessibility of the benefits of climate adaptation. This acknowledgment included recognition of past injustice and institutional marginalization. While the plan touted the benefits of climate adaptation it also explicitly acknowledged how some of the investments involved could "attract new residents, which can increase gentrification and displacement pressures on existing residents." The *Climate Action Plan* provides an Equity Implementation Guide which included a variety of resources for mitigating the impacts of gentrification.

Procedural Justice

While Portland's plan identified tenets of procedural justice as an essential step in addressing the inequalities identified, there is little evidence that effort was made to include the community in the construction of the plan. For example, the plan noted "An essential step to addressing these inequities is to create opportunities for people most impacted to be at the table for today's decisions. That can only happen if policymakers and members of under-represented and under-served communities know each other, trust each other and work collaboratively toward common interests and priorities." However, beyond this assertion, the plan does not outline any steps taken to ensure under-represented and/or under-served communities played a role in constructing the plan or defining the problems addressed in the plan. While the stakeholder engagement process for the Equity Workgroup was described, there was little information available about how the *Climate Action Plan* Steering Committee was created or what role the stakeholders played in problem definition. Additionally, the plan did not provide any details about how information about the plan was disseminated or how public participation in plan creation, evaluation, and monitoring took place.

Chapter Five: Quantitative Analysis

To evaluate the impact green infrastructure as a climate resilience tool has on gentrification, I build on the qualitative research with a quantitative approach.

Data and Methodology

To measure the relationship between green infrastructure investment and gentrification in these three cities, I looked at whether gentrification occurred in eligible census tracts with the implementation of new green infrastructure during the period between 2010 and 2019. My dependent variable (gentrification) includes three components: (changes in) median income, median housing value, and proportion of residents with a 4-year college degree within a census tract (I discuss my operationalization of this variable below). I evaluated these trends at the census tract level because it provides a unit of analysis with data consistently collected by the American Community Survey. While this analysis could have been done with census block data[2], the margins of error are much larger for census block data than census tract data and boundaries for census blocks are more variable than census tracts, introducing several additional layers of data verification and complication (Spielman, et al., 2014). Additionally, several studies evaluating the relationship between urban greening and housing values have used census tract level data and successfully measured significant connections (Rigolon, & Németh, 2020; Netusil, et al., 2014).

[2] A census block is the smallest geographic unit used by the United States Census Bureau. Census blocks are grouped into block groups, which are grouped into census tracts. Blocks are typically bounded by roads and highways, town/city/county/state boundaries, creeks and rivers, etc.

Data

Data for this research was collected from several sources. Data for the demographic characteristics (DP05), income (S1901), housing (DP04), and education attainment (S1501) of the population were obtained from the U.S. Bureau of the Census's American Community Survey (ACS). This research uses the ACS 5-year estimate to establish a baseline for all census tracts in 2010. I then used annual ACS data for each year 2011 – 2019 at the census tract level for each city.

I obtained green infrastructure data from each city. The green infrastructure project data for Washington D.C. was produced by the Department of Energy and Environment in Washington D.C. and obtained from the D.C. Open Data Catalog. The green infrastructure for Portland, Oregon was provided by the Bureau of Environmental Services of the City of Portland. The green infrastructure data for Houston, Texas was provided by Houston – Galveston Area Council (H-GAC).

Variables

The table below outlines each variable included in the model, a brief description, and the source of the data. Below I provide more detailed descriptions of how these variables were constructed.

Table 3: Variables of interest

Variable	Description	Source
Gentrified	Outcome variable indicating a census tract saw a 10% increase in two of the three indicator variables	ACS DP04; ACS DP05; ACS S1501; ACS S1901
GI Dummy	Binary Independent Variable indicating whether a census tract had new green infrastructure implemented in a given year	Washington D.C. Open Data Catalog; City of

		Portland PortlandMaps; H-GAC
Lagged GI	Binary Independent Variable indicating whether a census tract had new green infrastructure implemented in the year prior	Washington D.C. Open Data Catalog; City of Portland PortlandMaps; H-GAC
GI	A continuous variable of the cumulative green infrastructure implemented in a census tract during a given year	Washington D.C. Open Data Catalog; City of Portland PortlandMaps; H-GAC
Population	Total population	ACS DP05
Adult Population	Total adult population (over 18 yo)	ACS DP05
White	Percentage of population that is white	ACS DP05
Black	Percentage of population that is black	ACS DP05
Native	Percentage of population that is Native Alaskan or American Indian	ACS DP05
Asian	Percentage of population that is Asian	ACS DP05
Pacific	Percentage of population that is Pacific Islander	ACS DP05
Other	Percentage of population that is race other	ACS DP05
Mixed	Percentage of population that is multiracial	ACS DP05
Hispanic	Percentage of population that is Hispanic	ACS DP05
Bachelors	Percentage of population over 25 with a bachelor's degree or more	ACS S1501
Income	Household annual income measured in 2019 USD	ACS S1901
Unit	Number of housing units	ACS DP04
Vacant Units	Percent of housing units that are vacant	ACS DP04
Median House Value	Median House Value in 2019 USD	ACS DP04

Using the data from the ACS, I identified which census tracts were eligible to gentrify in 2010. It is important to distinguish between census tracts that are gentrification eligible from those that are not because, while increasing values in already high-value neighborhoods or rising incomes in already high-income neighborhoods may be considered neighborhood change, it does not constitute gentrification (Bates, 2013, p. 28). By definition, gentrification considers the appreciation of neighborhoods that started, during our study period, as low or moderate-income. Based on metrics and practices identified in the literature, I coded census tracts as "gentrification-eligible" if their 2010 median income was in the lowest four deciles (Mujahid, 2019; Rigolon & Nemeth, 2020). I used the "gentrification-eligible" tracts of each city as my sample.

To measure whether or not a census tract gentrified, I used census data to construct a multidimensional binary variable indicating gentrification outcomes. While there are several validated methods of quantifying gentrification, different variable selections have a large impact on the outcomes of identifying neighborhoods undergoing gentrification (Easton, et al., 2020, p. 288). The Freeman Method is considered a reliable indicator of gentrification because it utilizes several markers to signal neighborhood change, including median income, housing age, urbanity, and education attainment, which are all rooted in a strong conceptual framework (Mujahid, et. al, 2019). The use of a multi-dimensional operationalization of gentrification has been more common in recent research as analysts recognize the complex range of relationships between social and economic neighborhood change (Easton et al, 2020, p. 288). The most common combination of variables includes the change of income, education level, and home values (Maciag, 2015; Desmond & Gershenson, 2017; Rigolon & Nemeth, 2020).

Based on literature and empirical research to support the working definition of gentrified, I used a variation of the Freeman Method (2005) to measure whether a census tract has gentrified (Chapple et al. 2017; Rigolon & Nemeth, 2020). My measurement of gentrification includes increases in median income, median housing value, and proportion of residents with a 4-year college degree. If a "gentrify eligible" census tract saw a 10% increase in two of those indicators from one year to the next (1 if yes, 0 if no), it was coded as having gentrified. The goal of this measurement is to capture both the in-migration of "gentrifiers" and the out-migration of longtime residents, as well as the housing market appreciation that can drive much of these demographic changes (Bates, 2013, p. 28). By including education attainment, this operationalization identifies the well-educated professionals migrating into the neighborhood who may have not yet reached their peak earning years but will contribute to the class composition shifts (Hammel, 1996, p. 255).

Using the green infrastructure data for each city, I created a dummy variable indicating whether or not a census tract had a green infrastructure project implemented in a given year. When a data source for green infrastructure included public and privately funded green infrastructure, such as with Washington, D.C., I excluded all privately funded projects to only evaluate the impact of green infrastructure implemented by the state, local, or federal government.

Other variables used as covariates include racial demographics, property vacancy rates, and population size. I based the use of these variables as control covariates on the literature on measuring neighborhood change and gentrification (Rigolon & Nemeth, 2020).

Model Specifications

To estimate the impact of green infrastructure investment on gentrification in these three cities, I use a generalized estimating equation (GEE) model with an exchangeable correlation structure. GEE models are best for well-balanced datasets that span a short time period (Horton, 2001). This model provides a more nuanced estimate that does not rely on a precise covariance structure specification as likelihood-based linear models do. The idea of GEE is to average over all subjects and make a good guess on the within-subject covariance structure. I use an exchangeable correlation structure because I expect my dataset to have correlation across units – for example, green infrastructure in one tract could impact migration to/from its neighboring tracts. A GEE model with exchangeable correlation allows me to control for such spatial correlation in my estimates.

Because the literature indicates that gentrification occurs on delay ranging from three to six years, I use lagged independent variables to measure the impact of green infrastructure investments (Donovan, et al., 2021). Rather than including multiple lags, which will exhibit high collinearity with each other, in one model I execute four GEE models, where a 3-, 4-, 5- and 6-year lag of gentrification are controlled for. I also utilize time dummies to control for omitted variables that vary over time but affect census tracts similarly (i.e. general shocks in the real estate market). This is particularly important because my time period (2010 – 2019) overlaps with dramatic changes in the housing and (subprime) mortgage markets, as well as the Great Recession. Finally, I include variables measuring race, size of the adult population, and housing vacancy rates to further control for extraneous variables that may correlate with gentrification and eclipse the relationship between green infrastructure and gentrification.

Hypotheses

Based on the literature and the final regression model above, I hypothesize that the coefficient on lagged green infrastructure investment will be positive and significant. In other words, I expect census tracts that received more green infrastructure investments in years prior will be more likely to exhibit gentrification outcomes. I also expect that cities with higher equity scores from the qualitative analysis of resilience plans will be less likely to have gentrification or will have less significant relationships between green infrastructure and gentrification.

Findings

Descriptive Findings

Each city has a different relationship with green infrastructure. Table 4 displays data regarding the number of gentrification-eligible tracts, green infrastructure projects, and gentrification outcomes.

Table 4: Descriptive statistics of each city

City	Gentrification-eligible Census tracts	Green infrastructure projects	Gentrification outcomes by 2019
Washington, D.C.	70	1009	18
Houston, Texas (Harris County)	314	24	199
Portland, Oregon	67	729	47

Regression Results

Washington, D.C.

Washington, D.C. saw a total of over 1000 green infrastructure projects through its 70 gentrification-eligible census tracts between 2010 and 2019. Table 5 displays the impact of green infrastructure on gentrification as estimated by four independent GEE models using the GI dummy variable lagged for three to six years.

Table 5: Impact of Green Infrastructure on gentrification displayed in log odds from the GEE model in Washington, D.C.

Variable	3 Year Lag of GI	4 Year Lag of GI	5 Year Lag of GI	6 Year Lag of GI
L3. GI	1.0545***			
L4. GI		0.6174*		
L5. GI			0.644	
L6. GI				0.4558
Adult Population	-0.0001	-0.0001	-0.0001	0.000
White population	-0.012	-0.0438	-0.066	-0.1816
Black Population	-0.0017	-0.0351	-0.0562	-0.1679
Native Population	-0.436	-0.4421	-0.6816*	-0.6436
Asian Population	-0.0024	-0.0176	-0.0451	-0.2103
Pacific Islander Population	-0.4351	-0.39	-0.6762	-0.8126
Multiracial Population	-0.0045	-0.0543	-0.0749	-0.1953
Vacant House Ratio	-0.0148	-0.0055	-0.0224	-0.012
Census Tract Dummy Variable	-0.0064	-0.0052	-0.01	-0.0077
Constant	-1.0613	2.4877	4.9821	15.7956
N	490	420	350	280

Legend: * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.01
N-1 yearly dummies are included in the regression model but not shown

The relationship between green infrastructure and gentrification is strongest three- or four-years post-installation. The coefficients on L3.GI and L4.GI indicates that a census tract is significantly more likely to gentrify if there was a green infrastructure project installed three or four years prior. Further analysis of this relationship using predicted probabilities produced from this model show that a census tract with a green infrastructure project has a 17 percentage points higher likelihood of gentrifying within three years than a census tract without a green infrastructure project, all else held constant. This relationship is significant on the 99% confidence level.

Houston, Texas

Houston's relationship with green infrastructure, as discussed, is much newer than Washington, D.C.'s. Across the 314 census tracts within Harris, County Texas that were gentrification eligible, there were only 24 green infrastructure projects during the period of 2010-2019. Table 6 displays the relationship between green infrastructure installations and gentrification using a lagged independent variable for years three to five. This set of models does not include a model using a 6-year lag of green infrastructure because this lag suffered from quasi-separation - the 6th lag of the green infrastructure dummy variable perfectly predicts a lack of gentrification, which resulted in this lag being dropped when the GEE model was executed, as well as all observations whose lack of gentrification was perfectly predicted by this lag.

Table 6: Impact of Green Infrastructure on Gentrification displayed in log odds from GEE in Houston, Texas

Variable	3 Year Lag of GI	4 Year Lag of GI	5 Year Lag of GI
L3. GI	0.4298		
L4. GI		0.8143	
L5. GI			0.2944
Adult Population	0	0	0
White population	0.0088	0.0068	0.0071
Black Population	0.0083	0.0054	0.0037
Native Population	-0.0297	-0.0291	-0.0268
Asian Population	0.0219**	0.0158	0.0173
Pacific Islander Population	0.0366*	0.0337	0.0347*
Multiracial Population	-0.0042	-0.0043	-0.0047
Vacant House Ratio	0.0214**	0.0254***	0.0286***
Census Tract Dummy Variable	0.0027***	0.0029***	0.0029***
Constant	-3.7436***	-3.3301***	-3.1878***
N	2198	1884	1570

Legend: * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.01
N-1 yearly dummies are included in the regression model but not shown

Variable	3 Year Lag of GI	4 Year Lag of GI	5 Year Lag of GI	6 Year Lag of GI
L3. GI	-0.4841			
L4. GI		0.0021		
L5. GI			0.4341	
L6. GI				0.9750***
Adult Population	-0.0005	-0.0003	-0.0002	0.0004
White population	0.0003	0	0	-0.0005
Black Population	0.0012	0.0011	0.0009	0.0003
Native Population	-0.0013	-0.0005	0.0001	-0.0003
Asian Population	0.0003	-0.0001	-0.0002	-0.0009
Pacific Islander Population	0.0029	0.0031	0.0029	0.0028
Multiracial Population	0.0009	0.0009	0.0007	-0.0001
Vacant House Ratio	-0.0092	-0.0201	-0.0487	-0.0518
Census Tract Dummy Variable	0.0034	0.0051	0.0068	0.0034
Constant	-2.1987***	-2.2199***	-2.1095***	-1.8551**
N	469	402	335	268

Legend: * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.01
N-1 yearly dummies are included in the regression model but not shown

Houston does not appear to suffer from gentrification as a result of green infrastructure investments. The lack of significance of the coefficients for lagged-GI indicates that there is not a strong relationship between green infrastructure investments and gentrification.

Portland, Oregon

Like Washington, D.C., Portland, Oregon has a longer history of green infrastructure use than Houston, Texas. Across the 67 gentrification-eligible census tracts, Portland installed over 700 green infrastructure projects between 2010 and 2019. Table 7 displays the relationship between green infrastructure and gentrification in Portland, Oregon.

Table 7: Impact of Green Infrastructure on Gentrification displayed in log odds from GEE in Portland, Oregon

Gentrification as a result of green infrastructure appears in the 6th lag of the green infrastructure dummy variable, indicating that it takes 6 years for green infrastructure to produce gentrification. This relationship is significant on the 99% confidence interval and, using predicted probabilities produced from this estimator, tells us that a census tract that received a green infrastructure project is 14.9 percentage points more likely to gentrify within six years than a census tract that did not receive a green infrastructure project.

Model Robustness

To check the robustness of my estimator, I ran several alternative models with similar specifications. Because GEE models require specification of correlation structure, I test my specifications with GEE models that use two other correlation structures: autoregressive and pair-wise. The autoregressive correlation structure controls for temporal correlations while the pair-wise correlation structure uses no specification and estimates from the data without restriction. These models can be found in the appendices (Appendix B and C).

I further evaluated the robustness of my primary model by creating an index variable measuring gentrification with the growth rates of income, education level, and home values. This index is the sum of the standardized values of year-on-year growth in these three components – values above 0 indicate that gentrification-eligible tracts are experiencing growth rates across income, education, and housing values that are higher than the average. Figure 1 displays the distribution of this index by each city.

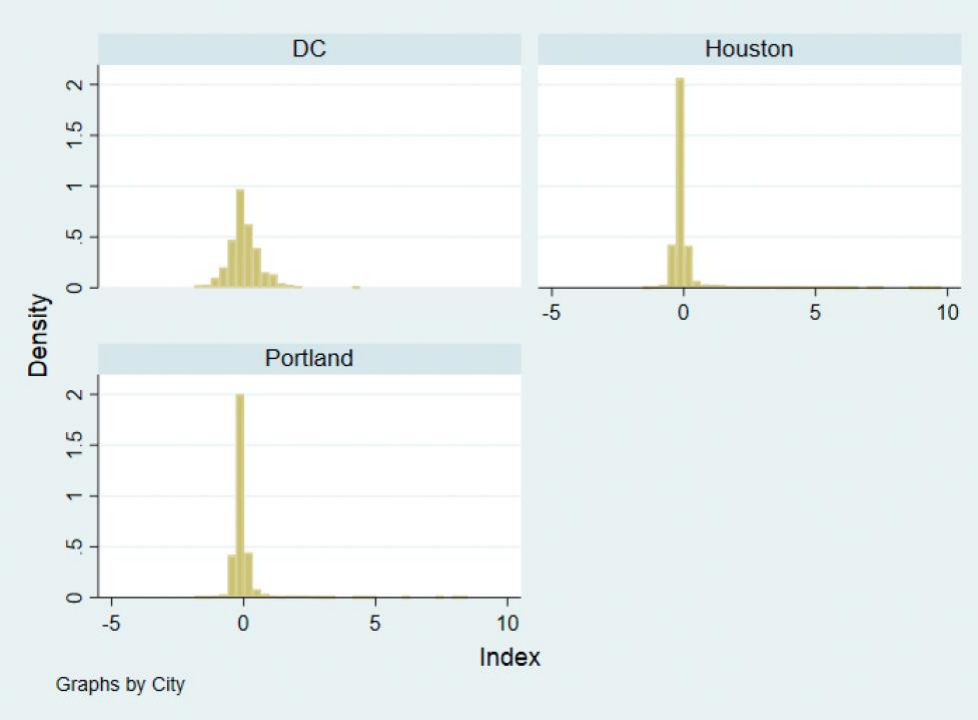

Figure 1: Histogram of each city's gentrification index variable

This display of histograms (Figure 1) shows how the index variable is distributed within each city. Each city has some census tracts with particularly high index scores (between 5 and 10), indicating that gentrification is particularly pronounced in those tracts. Overall, however, these histograms show that the index is normally distributed.

I then use this index variable as the dependent variable of an OLS model with panel corrected standard errors (PCSE). PCSEs upwardly adjust understated error variances produced by heteroskedasticity and contemporaneous correlation in linear models. Additionally, as noted above, spatial correlation is likely in this dataset, so I control for census tract dummies. Tables 8, 9, and 10 display the results of the PCSE models for Washington, D.C., Houston, Texas, and Portland, Oregon respectively.

Table 8: D.C. - Impact of Green Infrastructure on Gentrification using PCSE Model

Variable	3 Year Lag of GI	4 Year Lag of GI	5 Year Lag of GI	6 Year Lag of GI
L3. GI	0.2987***			
L4. GI		0.3011***		
L5. GI			0.2409*	
L6. GI				0.3822**
Adult Population	0	0	0	0
White population	0.0077	0.0099	-0.0139	-0.0328
Black Population	0.0085	0.0122	-0.0116	-0.0258
Native Population	-0.0348	-0.0258	-0.0514	-0.1056
Asian Population	0.0047	0.0108	-0.0177	-0.0281
Pacific Islander Population	0.2051	0.1919	0.1762	0.183
Multiracial Population	0.0115	0.0136	-0.014	-0.027
Vacant House Ratio	-0.0053	-0.0026	-0.0069	-0.0085
Census Tract Dummy Variable	-0.0011	-0.0011	-0.0026***	-0.0030***
Constant	-1.0222	-1.196	1.3777	2.763
N	490	420	350	280

Legend: * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.01
N-1 yearly dummies are included in the regression model but not shown

The findings displayed in Table 8 confirm the strong relationship between the 3rd and 4th lag of green infrastructure and gentrification. Both coefficients are positive and significant as predicted and as shown with the GEE model.

Table 9, displaying the results of Houston, further confirm the lack of a significant relationship between green infrastructure and gentrification in this case study. None of the lagged variables are significant in this model, similar to that of the GEE model for Houston, Texas.

Table 9: Houston - Impact of Green Infrastructure on Gentrification using PCSE Model

Variable	3 Year Lag of GI	4 Year Lag of GI	5 Year Lag of GI	6 Year Lag of GI
L3. GI	0.0853			
L4. GI		-0.0977		
L5. GI			0.244	
L6. GI				-0.2085
Adult Population	0.000	0.000	0.0000*	0.000
White population	0.0076	0.0081	0.009	0.0120**
Black Population	0.0047	0.0048	0.0052	0.0072**
Native Population	-0.0021	-0.0026	-0.0041	-0.0682*
Asian Population	0.0117	0.013	0.0156	0.0162
Pacific Islander Population	-0.0049	-0.0058	-0.0063	0.0489
Multiracial Population	0.0091**	0.0100**	0.0111*	0.0469*
Vacant House Ratio	0.0029	0.0046*	0.0057*	0.0082**
Census Tract Dummy Variable	0.0016	0.0018	0.0022	0.0025
Constant	-1.0982**	-1.1490**	-1.3542*	-1.6734***
N	2198	1884	1570	1256

Legend: * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.01
N-1 yearly dummies are included in the regression model but not shown

Table 10 displays the OLS model as a robustness test for Portland, Oregon's findings. This model shows that a continuous variable measuring gentrification can reveal a relationship between green infrastructure and gentrification at the 4th and 5th lag, as well as the already established 6th lag. An OLS model may be detecting gentrification earlier because it can measure a more nuanced operationalization of gentrification due to the use of a continuous outcome variable instead of a binary variable. This model confirms the findings of the GEE model above while also expanding on findings by indicating that gentrification could show up as early as four years after a green infrastructure project is installed.

Table 10: Portland - Impact of Green Infrastructure on Gentrification from PCSE Model

Variable	3 Year Lag of GI	4 Year Lag of GI	5 Year Lag of GI	6 Year Lag of GI
L3. GI	-0.0089			
L4. GI		0.2649**		
L5. GI			0.1366*	
L6. GI				0.2696***
Adult Population	0	0	0.0001	0.0003
White population	-0.0001	-0.0001	-0.0002	-0.0004
Black Population	0.0002	0.0002	0.0002	0.0001
Native Population	0.0001	0.0002	0.0002	0.0002
Asian Population	0.0001	0	-0.0001	-0.0003
Pacific Islander Population	0.0004	0.0003	0.0004	0.0004
Multiracial Population	-0.0002	-0.0002	-0.0003	-0.0005
Vacant House Ratio	-0.001	-0.0034	-0.0039	-0.0015
Census Tract Dummy Variable	0.0044	0.006	0.0062	0.0074
Constant	-0.2209	-0.2216	-0.0957	-0.0632
N	469	402	335	268

Legend: * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.01
N-1 yearly dummies are included in the regression model but not shown

Chapter Six: Discussion and Implications

Working in tandem, the qualitative and quantitative findings of this comparative case study provide several key takeaways regarding the equity and justice considerations of climate resilience planning. First and foremost, the qualitative findings indicate that these three cities are not incorporating equity and justice into their climate adaptation and resilience planning in robust or comprehensive ways. Meanwhile, the quantitative findings shed light on how green infrastructure, a tool for climate resilience building in urban environments, can contribute to inequitable outcomes, namely gentrification. While there could be several explanations for the different impacts of green infrastructure on gentrification outcomes in each city, it is important to consider how the construction and implementation of resilience strategies relate to these findings.

Washington D.C. scored the lowest out of all three cities and displayed the strongest relationship between green infrastructure implementation and gentrification. It is notable that Washington D.C.'s resilience strategy was weakest in the areas of distributional justice, namely acts of omissions. This might be intuitive if the analysis focused on the environmental justice component of allocating green infrastructure investments. However, this analysis is more focused on acts of commission in the form of gentrification as a result of green infrastructure. It may be surprising, then, that Washington D.C. scored fairly high in the acts of commission section of the recognitional and distributive justice rubric. Washington, D.C.'s strategy actively acknowledged the role increased investments could play in gentrification, saying the Resilience strategy will "Proactively invest in anti-displacement strategies, recognizing the economic pressures that often accompany increased investment" (p. 35). However, D.C.'s score on the

monitoring and evaluation section may shed some light on the discrepancy between the goals of the resilience strategy and the outcomes of gentrification. First, it is important to note that this rubric and analysis does not address the follow-through efforts of cities, meaning I do not evaluate how effectively these strategies are implemented. Second, Washington, D.C.'s strategy did not outline detailed processes for monitoring the implementation or collaborating with the public to evaluate outcomes. This is an important part of equitably building resilience and could be a contributing factor to the outcome of gentrification.

This pattern is not evident in the results for Portland's resilience strategy and gentrification outcomes. Portland, Oregon scored best in the recognitional and distributive section but suffered in the procedural justice categories. This indicates that while the strategy adequately acknowledged ways specific communities and stakeholders have elevated vulnerability due in part to municipal systems and socioeconomic factors, there was not an active process to rectify this injustice within the process of constructing the strategy. In many ways, this indicates that Portland, Oregon's equity and justice lens was effective only at discussing equity and justice rather than implementing it. Further supporting this pattern is the low score for monitoring and evaluation, showing how little collaboration with the public was prioritized after the strategy was finalized. These findings are drawn from the content analysis aligned well with the quantitative findings showing an increased level of gentrification in census tracts that received green infrastructure.

Finally, some conclusions can be drawn from the lack of gentrification occurring in Houston's census tracts that had green infrastructure investment. Viewed alongside the content analysis, we can see how it is possible that Houston, which had the highest overall score, was

most successful at implementing an equity and justice framework in congruence with the formation and implementation of their resilience strategy. This is particularly poignant when looking at the much higher score in transparency and participation, indicating that Houston was more successful in creating an inclusive and collaborative process of constructing the strategy.

Looking only at outcomes from the quantitative analysis using the panel data from 2010-2019, this research indicates that implementing green infrastructure increases the odds that an area—in this study, a census tract—will gentrify in Washington, D.C. and Portland, Oregon, but not in Houston, Texas. In both D.C. and Portland, this increase in the likelihood of gentrification is significant and of a large magnitude but in different timeframes. For example, Portland will not see this impact on gentrification until six years after the green infrastructure was implemented, while the impact will occur in D.C. in only three years. This could be a sign that neighborhood characteristics—i.e. ratio of residents with bachelor's degrees, home values, and income levels—are less elastic in Portland, Oregon than in Washington, D.C.

The implications of insignificant findings in the Houston analysis are not trivial. Houston is an important and interesting case study precisely due to its characteristics that are contrary to that of Portland and D.C. While all three cities are cultural, economic, and residential hubs in their regions, Houston has the largest population and the largest land coverage. Importantly, while Portland and D.C. have enacted initiatives and zoning laws to limit the amount of urban sprawl in the regions, Houston is distinguished for its lack of zoning laws. We should not ignore the role municipal zoning has on how green infrastructure impacts the occurrence of gentrification. It is possible that the vast difference in zoning laws between Houston Texas and

the other two cities contributed to the different outcomes of gentrification. In many ways, this comparative case study highlights the tradeoffs between urban sprawl and gentrification.

Policy Recommendations

Evidence that green infrastructure implementation can contribute to gentrification should not be used to deter the use of green infrastructure for climate resilience building but should instead provide insights on the importance of integrating a robust equity and justice lens in all urban resilience planning. As communities contend with the impact of climate change on cities and residential areas, planners and policymakers should utilize every tool available, including policies that mitigate the increased housing burden that may result from infrastructure investments.

Preventing Gentrification

The phenomenon of gentrification is not unique to green infrastructure. Many different urban revitalization programs, community development projects, or reinvestment initiatives can cause gentrification (Bates, 2013). Likewise, there are many proposed policy interventions to prevent or mitigate gentrification. A common and well-supported approach is to supplement revitalization initiatives with the aggressive promotion of middle-to-low-income housing construction. A major component of this approach should be the use of inclusionary zoning (IZ) to ensure access and availability of affordable housing units (Bates, 2013; Schwartz, et al, 2012). This may be in the form of mandatory IZ where possible or incentive-based voluntary inclusionary housing. Policymakers should also consider policies that help long-time residents stay in their homes even if gentrification does occur, such as stabilization vouchers, rent caps, or property tax reduction.

Finally, in the context of green gentrification, several researchers have promoted the "just green enough" approach, first outlined by Curran and Hamilton (2012), which promotes urban greening only that allows communities to reap the health and resilience benefits while avoiding the speculative development that can deteriorate the social fabric of the community and kickstart gentrification (2012; Wolch et al., 2014). In practice, this may involve smaller greening projects that are spread throughout the cities and incorporating the green infrastructure into the neighborhood without shifting the social cohesion and allowing for some uses to remain unchanged for the explicit purpose of maintaining a working-class population (Curran & Hamilton, 2012, p. 1039).

Equity Frameworks for Green Infrastructure

While the efficacy of green infrastructure as a resilience tool is beyond the scope of this study, there is ample existing research indicating that green infrastructure can be an effective way to mitigate the intensity or even prevent urban flooding events (McPhillips, & Matsler, 2018). Therefore, it is worth investigating ways green infrastructure can be used without exacerbating housing instability and while promoting equitable outcomes.

One policy approach, introduced by Heckert and Rosan, discussed recently in the literature is the construction and utilization of a GI Equity Index (2016). Many authors promote using an index to value the ancillary benefits GI offers while also operationalizing the discrepancies in the access to these benefits as a way to make community planning decisions (Hoover & Hopton, 2019). Using an index could also provide planners and decision-makers with the flexibility to incorporate the community-needs and desires that may be unique in each neighborhood. For example, the equity index described in Heckert and Rosan's work allows

users to weight ancillary benefits based on how needed or desired they are in a specific community; therefore, if a community views lack of park access as a major source of their "equity void," they could weight this factor or benefit higher as a way to influence the allocation decisions and the choices between types of GI projects (Heckert & Rosan, 2016). This also promotes a more community-driven management scheme instead of the central planning that is used in most urban planning decisions.

Other frameworks discussed in developing GI research suggest approaches to balancing the stormwater management role of GI with the ancillary benefits that may be contributing to outcomes discussed in this paper. A major takeaway from these approaches, such as the framework outlined by Hoover and Hopton (2019), is the need for stakeholder engagement and the role of communities in problem definition. As outlined throughout the results of this study, cities have struggled with adequately incorporating community voices into the decision-making process for resiliency planning as a whole and green infrastructure implementation specifically. This focus on the needs and voices of the community within planning decisions is consistent with a more general environmental justice framework and will, at the least, allow for community buy-in and the elevation of community concerns.

Incorporating Equity and Justice in Resilience Planning

The relationship between green infrastructure and gentrification that is established in this research highlights an overall connection between resilience planning and equity outcomes. As communities develop contingency plans and mitigation strategies for climate change, it is crucial to consider the populations already at an elevated risk and how policies meant to build resilience could exacerbate existing vulnerabilities or even introduce new vulnerabilities. This is a lesson

not unique to green infrastructure as a resilience-building tool. This research, and the literature it is building upon, exemplify how important it is to incorporate an equity and justice lens into climate resilience planning. This should not be a supplemental component of resilience planning or an afterthought of climate mitigation but should be integrated fully into every step of creating, implementing, and monitoring climate resilience strategies.

Limitations

This study takes on many intertwining topics and therefore comes with some limitations, including the operationalization of variables, the limited scope of the comparative case studies, and the inclusion of city-wide characteristics. This research looks at the impact of green infrastructure on gentrification by looking at changes in median income, median housing value, and the proportion of residents with a 4-year college degree in census tracts with green infrastructure. However, as discussed earlier, this operationalization of gentrification is a methodological choice based on available literature and data. There are many different ways to quantify and define gentrification. Other definitions and operationalizations of gentrification may produce different or more nuanced results.

Additionally, the use of a comparative case study with mixed methods provides many valuable insights but also limits the scope of the evaluation. While this study provides findings and insight on the role of green infrastructure on gentrification in Washington, D.C., Houston, Texas, and Portland, Oregon, the results may not be generalizable to other urban areas or communities across the country or worldwide. Further research is needed to validate these findings and their generalizability.

Likewise, this comparative case study was only able to look at the relationship between green infrastructure and gentrification, while controlling for characteristics across census tracts. Because I only evaluate three cities, I was not able to evaluate the role of city-wide characteristics in-depth or with a quantitative model. A larger comparative case study or a cross-sectional study of many cities could look at the influence city-wide variables such as zoning policies have on the relationship between green infrastructure and gentrification. This was beyond the scope and capabilities of this study but should be handled in further research.

Finally, this study does not evaluate displacement as a result of green infrastructure. While the outcomes of this research show that gentrification can occur due to increased investments in green infrastructure, it does not measure how much the changes in median income, median housing value, and proportion of residents with a 4-year college degree contribute to neighborhood change in social cohesion or displacement. Future research should look closer at how green infrastructure impacts displacement in addition to gentrification.

Conclusion

Disparities in vulnerability to climate change impacts have been repeatedly identified in environmental justice research. This research highlights how communities that have an elevated risk to climate change and a need to build urban resilience can be negatively impacted by the implementation of resilience tools, such as green infrastructure for flood risk reduction, if policy initiatives and resilience strategies do not effectively address the origins of vulnerability. Communities that are particularly vulnerable to the effects of climate change due to socioeconomic factors are similarly vulnerable to changes in neighborhood characteristics that may come from increased investment in the area. In that way, the implementation of green

infrastructure, even when attempting to build resilience to climate threats like flooding and the urban heat effect, can exacerbate community vulnerabilities by increasing the housing burden on existing residents. This is evident from the significant relationship between green infrastructure investments at gentrification in Washington, D.C., and Portland, Oregon, particularly three years or more after the implementation. Using a more equitable, inclusive, and just process to design resilience strategies and implement green infrastructure projects may help mitigate the impacts of this relationship. However, ultimately, policymakers will need to address the origins of vulnerabilities, including socioeconomic disparities and unequal opportunities for economic resilience, to build urban climate resilience equitably and for all residents.

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Appendices

Appendix A

Appendix A: Justice and Equity Resilience Strategy Evaluation Framework

Criteria Code		Points assigned
Recognitional and Distributive Justice		
Acts of Omission		
1	Are specific populations of interest *(e.g. vulnerable groups)* identified in the strategy?	/1
2	- If so, is their vulnerability explored in-depth (e.g. historic or structural reasons for vulnerability)	/1
3	Is the strategy available in the predominant local language and/or minority languages?	/1
4	Are benefits intentionally directed at specific groups identified as vulnerable?	/1
5	Does the strategy acknowledge that some benefits may not be accessible to vulnerable stakeholders?	/1
6	- Does the strategy outline ways it will attempt to mitigate this or improve access?	/1
	TOTAL POSSIBLE POINTS:	/6
Acts of Commission		
7	Does the strategy acknowledge how proposed actions could negatively affect a vulnerable group?	/1
8	- If so, does the strategy propose actions to mitigate this impact?	/1
9	Does the strategy acknowledge previous acts of commission or injustice?	/1
	TOTAL POSSIBLE POINTS:	/3
Recognizing Vulnerability		
10	Is vulnerability explicitly defined and explained?	/1
11	- Does the strategy's definition of vulnerability include socioeconomic/sociocultural characteristics?	/1
12	Does the strategy acknowledge how municipal systems or processes might exacerbate vulnerability?	/1
13	- Does the strategy identify actions to mitigate this?	/1
14	- Does the strategy address root causes of vulnerability with these actions or do the actions attempt to treat rather than prevent vulnerability?	/1

15	Does the strategy feature a map that describes and identifies areas of socioeconomic vulnerability?	/1
	TOTAL POSSIBLE POINTS:	/6
Procedural Justice		
Transparency and Participation		
16	Is the stakeholder engagement process described?	/1
17	- Does the strategy describe during which phases participation took place?	/1
18	- Does the strategy describe methods (media, technology, context) of seeking consultation?	/1
19	- Does the strategy describe the quantity and demographic composition of people were consulted?	/1
20	- Does the strategy describe engaging stakeholders in early problem definition?	/1
21	- Does the strategy describe engaging stakeholders in solution generation?	/1
22	- Does the strategy describe how information was disseminated to the non-participant public?	/1
23	- Does the strategy describe what rationale was used to identify and recruit stakeholders? *(e.g. why some actors were included while others were not)*	/1
24	- Is there evidence that vulnerable groups were afforded an opportunity to self-identify their needs and priorities?	/1
25	- Were specific partnerships or arrangements achieved with key external stakeholders? *(e.g. civil society, associations, industry)*	/1
26	Are there plans for ongoing participation, or is the strategy portrayed as "finished"?	/1
	TOTAL POSSIBLE POINTS:	/11
Monitoring and Evaluation		
27	Does the strategy describe a framework for evaluating whether or not its actions have been successful?	/1
28	- Does it include equity considerations as an indicator of success/failure?	/1
29	Does the strategy mention that monitoring and evaluation protocol will be collaboratively designed?	/1

30	Is there an opportunity for public participation in conducting monitoring and evaluation?	/1
	TOTAL POSSIBLE POINTS:	/4
	GRAND TOTAL POSSIBLE POINTS:	/30

Appendix B

Appendix B: GEE models for Washington, D.C.

Variable	GEE AR-1	GEE Unstructured	GEE Exchangeable
L3. GI	1.0676***	0.9745***	1.0545***
Adult Population	-0.0001	-0.0001	-0.0001
White population	-0.0107	-0.053	-0.012
Black Population	-0.0004	-0.0461	-0.0017
Native Population	-0.4229	-0.4778*	-0.436
Asian Population	-0.0016	-0.0484	-0.0024
Pacific Islander Population	-0.4023	-1.0685	-0.4351
Multiracial Population	-0.002	-0.0622	-0.0045
Vacant House Ratio	-0.0139	-0.025	-0.0148
Census Tract Dummy Variable	-0.0064	-0.0058	-0.0064
Constant	-1.2091	3.479	-1.0613
N	490	490	490

Legend: * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.01
N-1 yearly dummies are included in the regression model but not shown

Appendix C

Appendix C: GEE models for Portland, OR

Variable	GEE AR-1	GEE Unstructured	GEE Exchangeable
L6. GI	0.9671***	0.9378**	0.9750***
Adult Population	0.0004	0.0002	0.0004
White population	-0.0006	-0.0004	-0.0005
Black Population	0.0002	0.0004	0.0003
Native Population	-0.0002	0.0003	-0.0003
Asian Population	-0.001	-0.0009	-0.0009
Pacific Islander Population	0.0027	0.0031	0.0028
Multiracial Population	-0.0001	0	-0.0001
Vacant House Ratio	-0.0525	-0.0606	-0.0518
Census Tract Dummy Variable	0.0029	0.0004	0.0034
Constant	-1.8446**	-1.6591**	-1.8551**
N	268	268	268

Legend: * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.01
N-1 yearly dummies are included in the regression model but not shown