Under What Conditions Can Urban Rail Transit Induce Higher Density?

Evidence from Four Metropolitan Areas in the United States, 1990-2010

by

Qingyun Shen

**A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Urban and Regional Planning)
in the University of Michigan
2013**

Doctoral Committee:

- **Professor Jonathan Levine, co-chair**
- **Associate Professor Joseph D. Grengs, co-chair**
- **Associate Professor Lan Deng**
- **Associate Professor David E. Thacher**

To Grandma

Acknowledgements

I owe enormous gratitude to my dissertation committee members. My committee co-chairs and advisors, Professors Jonathan Levine and Joe Grengs, with their expertise and knowledge, helped me to shape and refine my work in each and every step of this dissertation project. Out of their busy schedule, Jonathan and Joe both spared a generous amount of time to talk with me, read my drafts, give me comments, and write me recommendation letters for grant applications. They also offered me huge emotional support with the most encouragement and compassion. Professor Lan Deng is one of the earliest and continuing readers of my dissertation drafts, to whom I am very thankful. Ever since I began my master's studies at the University of Michigan eight years ago, Lan has been my mentor and taught me in so many different ways. She offered me my very first opportunity to be involved in a research project, walked me through the whole process and trusted me with every detail. Her intelligence and diligence motivate me to be a scholar and an educator just like her, and I always look up to her as my role model. Professor David Thacher, with his sharp insights and deep understandings of academic research, guided me to think outside of the box of making statistical inferences and to look at the bigger picture of the policy implications of conducting empirical studies, which becomes an essential part of this dissertation.

I also want to thank other faculty and staff members in the Urban and Regional Planning program at the University of Michigan: Professor Scott Campbell, for being a great resource during my doctoral years, offering me academic advice, preparing my fellowship applications, and sharing with me valuable stories and experiences of his own; Professor Robert Fishman, for standing in the general committee of my proposal defense and providing keen insights into my research design; Professor Gavin Shatkin, for reading the first drafts of my proposal and guiding me along the way to form a practical dissertation topic; Professors Larissa Larsen and Richard Norton, for being understanding, supportive and compassionate when I was on maternity leave; our program assistant Lisa Hauser, for being extremely helpful and patient, answering every question I have; and many other people in the A+A building from whom I benefit a lot, both in and outside of classes.

There are still many other people outside of the department who helped me with this dissertation. For assisting me with the collecting and processing of satellite images, I thank Jen Green and Karl Longstreth at the Clark Library and the SAND North Lab of the University of Michigan. For giving me comments when I presented my work at ACSP and other conferences, I thank Professor Qing Shen from the University of Washington-Seattle, Professor Ruth Steiner from the University of Florida. The Predoctoral Fellowship, the Barbour Scholarship, and several other travel and research grants I received from Rackham Graduate School at the University of Michigan provided essential financial support I needed to conduct my research.

It has been a really long journey towards the completion of this dissertation and my doctoral studies, and there were ups and downs along the way. Thanks to my fellow Ph.D. students in the URP program, with whom I had many intellectual conversations, relaxing happy hours, and delightful meals at potlucks, I managed to survive and enjoy this challenging yet rewarding journey. I am especially indebted to Xiaoguang, who greeted me warmly on the first day of my arrival at Ann Arbor eight years ago and became a true friend ever since. Xiaoguang is almost like a big sister, who offered me generous help and advice on everything from GIS tips to infant care. My sincere thanks also go to Xu Ying, a candid, caring, warm-hearted friend, who always stands beside me and makes me feel like home in her lovely house when I am writing this dissertation with finishing touches.

Last but not least, I am forever grateful to the three most important women of my life: my grandma, my mom, and my daughter. My daughter Ellie is like a little angel who brought endless happiness to my life. Thank you, Ellie. My mom raised me up almost all by herself and offered me everything she could over the years—care, comfort, trust, education, and above all these, love. Thank you, Mom. My grandma was the most kind and loving person I have ever known, who cared for me, in her own way, till the last minute of her life. She was also the first

person who encouraged me to pursue higher education and to become the first Ph.D. in our family. Thank you, Grandma. This work is dedicated to you.

Table of Contents

List of Tables

List of Figures

List of Maps

List of Abbreviations

ACS	American Community Survey
APTA	American Public Transportation Association
CATS	Chicago Area Transportation Study
CTA	Chicago Transit Authority
DART	Dallas Area Rapid Transit
DID	Difference in differences
FAR	Floor area ratio
FHWA	Federal Highway Administration
GIS	Geographic information systems
LACTC	Los Angeles County Transportation Commission
LACMTA	Los Angeles County Metropolitan Transportation Authority
MARTA	Metropolitan Atlanta Rapid Transit Authority
MHV	Median housing value for owner-occupied housing units
MPH	Miles per hour
NTD	National Transit Database
RTD	Regional Transportation District (Denver, CO)
SEPTA	Southeastern Pennsylvania Transportation Authority
TOD	Transit-oriented development
TRB	Transportation Research Board
VMT	Vehicle miles traveled
WMATA	Washington Metropolitan Area Transit Authority

Abstract

Ample empirical evidence shows that dense urban forms can promote rail transit use and reduce car dependence. However, evidence of the reverse causal link—the impact of urban rail transit investments on neighborhood land use forms — is less clear. Previous studies that evaluate the land use impacts of the urban rail transit systems yield mixed results on whether and how these systems could affect land use forms. Those mixed results suggest that the existence and magnitude of land use changes due to rail projects are likely influenced by certain contextual conditions, pertaining both to the project location and to its regional setting. It is the focus of this study to explore what those conditions are and to examine how they could affect the land use impacts of urban rail transit projects on the nearby neighborhoods.

Out of many dimensions that describe land use impacts, this research chooses to examine the changes in population and housing densities—the densification effects, in particular. After theorizing the mechanisms of the densification effects of urban rail transit, this study hypothesizes on the key factors that may interfere with such land use effects and tests those hypotheses in empirical studies. It takes into account both the internal and external factors that could interfere with the land use impacts of urban rail transit. The internal factors include the type of rail transit and the station features; the external factors include the pre-existing conditions of the neighborhoods where the rail stations are located. To provide the most recent evidence on this topic, this research selects four metropolitan areas in the United States as the study cases—Chicago, Denver, Los Angeles, and Washington, D.C., each of which constructed new urban rail lines in the 1990s. Applying a difference-in-differences design and a mixed methodology of spatial and regression analyses, this study quantifies the effects of new rail stations on neighborhood population/housing density changes and investigates the conditions that may promote or mitigate such effects.

The findings on individual cases show that a new rail transit station is more likely to help increase population and housing densities when it is introduced in a moderate-income neighborhood with a pre-existing condition of compactness and relatively few single-family houses. A cross-comparison of the results from the four difference cases reveals that heavy rail lines are more likely to trigger increase in population and housing density than light rail lines. In addition, the network effect also matters—a new urban rail line that is an extension to an existing rail transit network is more likely to promote density increase than a brand new urban rail system built from scratch.

This study contributes to the long-lasting debate on the costs and benefits of urban rail transit investments. It provides the most recent empirical evidence on the densification effects of urban rail transit in the United States. Furthermore, it is the first of its kind to systematically study the interference of both the internal and external factors of a new urban rail transit project on its potential land use impacts. The findings of this study can be used to help transit planners make informed planning decisions on the site selection of a new rail station in the future, if densification is one of their planning goals.

Keywords:

Sustainable transportation, heavy rail, light rail, density, land use effects, difference-in-differences, neighborhood impacts

Chapter 1: Introduction

After decades of transportation policy that mainly promotes automobile travel, the awareness of the environmental, economic, and social problems associated with excessive car travel emerged and grew among planners, environmental groups, and the general public in the United States. In this context, investments on public transit have gradually regained popularity on the agenda of transportation planning in many American cities since the late 1980s. As opposed to the relatively uniform automotive mode of transportation, public transportation is the collection of alternative travel modes available for the general public, including buses, trams and light rail, heavy rail, commuter rail and suburban railroads. Many planners would agree that rail transit has advantages over bus transit for its bigger potential on changing land use forms and guiding urban development in a more efficient and sustainable way (Black & Lane, 2012). Whether and how such an acclaimed potential can be reached and realized, however, is open to question.

From 1970 to 2010, around $100 billion were spent on the construction and expansion of urban rail transit systems in the United states (American Public Transportation Association, 2012). During this period, dozens of cities invested in building new urban rail lines, and more are in planning stages. Such a resurgence of the urban rail transit investments leads to a heated debate on the cost-efficiency of these projects. An essential part of this debate involves scholarly investigation into the land use impacts of these new urban rail projects, due to the high expectations on rail transit's potential to guide development. Despite the intensive research on this topic, there is still no strong or consistent evidence on the causal effect of the urban rail projects on land use changes. Probably the only thing we could be certain about the land use effects of urban rail investments is that they are *uncertain*.

Under such circumstances, this study aims to contribute to the current literature on this topic by theorizing the mechanisms of the land use effects of urban rail transit, hypothesizing on the key factors that interfere with such land use effects, and testing those hypotheses in empirical studies. This introduction chapter provides a brief on the settings of this research: clarifying the key terminology; summarizing the recent boom in urban rail transit investments in the U.S. and the cost-benefit debate that follows the boom; and explaining why the conditions on the densification effects of urban rail projects is worth scholarly investigation.

1.1 The working definition of "density" and "densification"

Density is one of the key issues in the planning field (Florida, 2003; Jacobs, 1961). There are many aspects and measures of density that could be of interest to this study: residential density, building density, development density, employment density, street density, to name a few. The term densification, accordingly, regards to the increase in density. Among all those measures, this study is particularly interested in the two measures of residential density—population density and housing density, in the discussion of the densification effects of urban rail transit. In this context, a neighborhood that experiences population densification is a neighborhood that has more people per square mile; a neighborhood that experiences housing densification is a neighborhood that has more housing units per square miles.

The rationale of choosing residential densification rather than other aspects of densification as the topic of interest here is that residential densification is the most influential density measure on transit use (Baldassare, 1981; Bramley & Power, 2009; Cervero & Kockelman, 1997; Dunphy & Fisher, 1996; Ewing & Cervero, 2001, 2010; Institute for Metropolitan Studies, 1994; Schimek, 1996a). In the classic literature on the transportation-land use connection, residential density is one of the most frequently mentioned land use factors that interact with transportation investments and travel behaviors.

However, choosing residential densification as the indicator of the densification effects in this research also has its drawbacks. Residential densification is only one of the possible ways through which a neighborhood could benefit from urban rail transit. In some cases, a new rail transit station may bring in more commercial or office development in a nearby neighborhood—a sign of rail transit causing land use benefits. However, higher commercial or retail or employment densities do not necessarily mean more people or more housing units in the neighborhood. If we only look at the residential density measures, we would overlook/underestimate the densification outcomes in that case. To mitigate this problem partially, this study will exclude the downtown area from the analysis, since downtown is expected to be the places where most commercial/retail/employment densification takes place. The technical details of how to exclude the downtown area will be discussed in the methodology section of Chapter 3.

1.2 The working definition of "urban rail transit"

Urban rail transit, in this research, refers to two particular types of public transportation systems used for transporting passengers: heavy rail and light rail. The American Public Transportation Association (APTA, 1994) defines these two modes as follows:

- Heavy rail: "An electric railway with the capacity for a 'heavy volume' of traffic and characterized by exclusive rights-of-way, multi-car trains, high speed and rapid acceleration, sophisticated signaling and high platform loading." Subways, elevated railways, and metropolitan railways (Metro) are all forms of heavy rail.

- Light rail: "An electric railway with a 'light volume' traffic capacity compared to heavy rail. Light rail may use shared or exclusive rights-of-way, high or low platform loading and multi-car trains or single cars." Streetcars, trolleys, and trams are all forms of light rail.

By definition, what heavy rail and light rail have in common is that they both move passengers on trains that use rights-of-way tracks within metropolitan areas. They do not use existing intercity railroads as do commuter rail and suburban railway lines, which are excluded from this study because of the focus on the "urban" development of this study.

There are two major differences between heavy rail and light rail. First, heavy rail systems always have exclusive rights-of-way that are usually underground or elevated, while light rail is not necessarily grade-separated. As a result, the capital cost of implementing a heavy rail line will normally be much greater than that of a light rail line. However, the exclusive rights-of-way routes allow heavy rail systems to have a higher travel speed than light rail ones. Typically, at-grade light rail systems travel at 10 to 20 miles per hour (mph) and grade-separated light rail systems travel at 20 to 30 mph. By contrast, the typical average overall speeds of heavy rail systems in the United States range from 25 to 40 mph (Southeastern Wisconsin Regional Planning Commission, 1998). Higher travel speeds mean higher accessibility to destinations. Therefore, it is reasonable to speculate that constructing a new heavy rail line would have larger impacts on location advantage and land values of the nearby neighborhoods than constructing a new light rail line, everything else being equal.

Another distinction between the two modes is that heavy rail usually has a larger capacity and longer trains than light rail. Therefore, heavy rail systems usually can carry more passengers per train than light rail systems. But the lesser weight and smaller scale of light rail also has its advantages. These attributes make it less costly than heavy rail in terms of operating and construction costs. Besides, a smaller scale means that it is possible for light rail lines to pass through city centers or other dense urban areas without necessarily going underground or elevated, allowing for more flexibility in route planning (De Bruijn & Veeneman, 2009).

It is worth noting that the boundary between heavy rail and light rail is blurring nowadays as more light rail systems are having larger capacities, more exclusive rights-of-way, and higher traveling speeds (McBrayer, 2003). Nevertheless, it is one of the research interests of this study to examine both types of systems and to study the potential of each to foster land use impacts.

1.3 The resurgence of urban rail transit investments in the United States

The energy crises in the 1970s and the global awakening of the limits to growth lead to the widespread reception of a new term—sustainability. The notion of sustainability calls for a development pattern "that meets the needs of the present without compromising the ability of future generations to meet their own needs." (World Commission on Environmental Development, 1987). By this definition, the energy-consuming auto-dependent urban form is not sustainable. As the vitality and merits of sustainable development becomes well-received, urban planners and urban policy makers start to seek alternative transportation modes and land use patterns.

The notable relationship between urban form and energy use led many planners to associate compact urban forms with sustainability (Bramley & Power, 2009; Gordon & Richardson, 1997; M. Jenks & Burgess, 2000; Mike Jenks, Burton, & Williams, 1996). Although some scholars are still skeptical of the desirability of compact cities, curbing low-density urban development has become one of the primary goals of planning practices in many regions (Bramley & Power, 2009). Progressive growth management strategies such as “Smart Growth” laid out guidelines and principles to achieve that goal (Duany, Plater-Zyberk, & Speck, 2001). Focusing on compact development in areas with improved public transport supply, smart growth strategies aim to direct growth into existing urban areas and to improve the viability of public transportation (Handy, 2005). It envisions a reduction in the extension of low-density suburban subdivisions as the predominant pattern of urban development by promoting transit-oriented development (TOD), urban infill, and downtown revitalization.

In practice, there is an emerging trend to shift the focus of transportation planning from the traditional mobility-oriented goal of providing fast transport to a holistic goal of managing a sustainable transportation system (Lee, 2010). Keeping the movement of goods and people as fast as possible is no longer the ultimate end. Rather, a transportation system with good access to various opportunities at destinations would be preferred (Levine, Grengs, Shen, & Shen, 2012). Planners expect that proper transportation policies and investments could guide urban development in a sustainable way. Under this notion, transportation policies would allow or even encourage alternative travel modes other than the automobile. It is in such a context that urban rail transit regained its popularity and the investments in new rail systems in many U.S. cities (Lane, 2008). Figure 1 on the next page lays out all the urban rail systems by their opening date on a timeline. It takes little effort to notice the dramatic increase in rail transit investments after 1970. Throughout the entire 180-year history of urban rail transit development in the United States, the number of new systems constructed in the recent 40 years is more than double of that in the first 140 years.

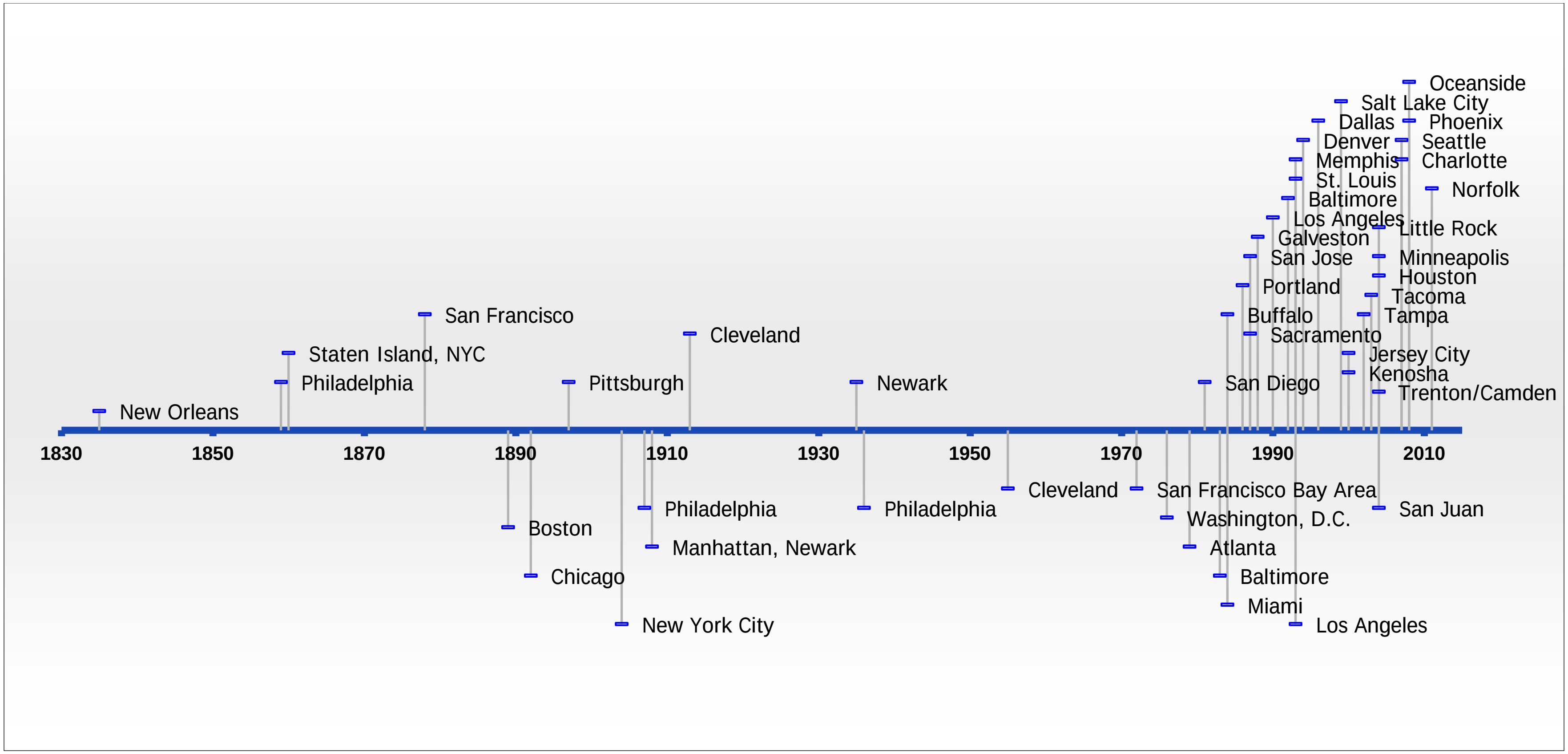


Figure 1: Timeline of the urban rail transit investments in U.S.[1]

Data source: American Public Transportation Association 2012 Fact Book, Appendix A, Table 3

[1] The date at which each city is labeled refers to the opening date of the first rail line in that city. Cities labeled underneath the time line refer to those with heavy rail systems. Cities labeled above the time line refer to those with light rail systems, including historic streetcars/ trams/ trolleys as well as modern light rail systems. Commuter rail and rural railroads are not shown in this chart. Whenever a city appears twice on the chart, that city includes both light rail and heavy rail systems and the initial opening date for each type is shown separately. Different lengths of callout lines are used in order to avoid overlapping labels on the chart. The height of these callout lines has no substantial meaning.

From 1830 to 1910, before the massive production of affordable automobiles came into being, about a dozen American cities had some type of rail transit, such as subways, streetcars, trams, or trolleys. At that time, urban rail transit was actually the leading public transportation mode. For the following six decades until 1970, the heyday of automobile dominance, many old rail systems were abandoned and only four American cities built new urban rail transit lines. Starting from the 1970s, urban rail transit projects gradually regained popularity: three cities opened new urban rail lines in the 1970s; eight cities opened new urban rail lines in the 1980s; another eight cities opened new urban rail lines in the 1990s; and thirteen new rail lines opened between 2000 and 2009. The combined capital costs on these urban rail investments, between 1970 and 2010, exceeded $100 billion (American Public Transportation Association, 2012), and it is expected that more cities will construct new urban rail lines in the next few decades (Miller, 2011).

1.4 The debate on the costs and benefits of urban rail transit

The recent resurgence of urban rail transit investments in many American cities has drawn the attention of scholarly investigations as well as public concerns. At the center of the discussions is a debate on the cost efficiency of urban rail transit projects (Atkinson-Palombo, 2010; Bhatta & Drennan, 2003; Cervero, 1994b; Lewis-Workman & Brod, 1997; Litman, 2004, 2012; Marshall, 2013; P. Nelson, Baglino, Harrington, Safirova, & Lipman, 2007; Skolnik & Schreiner, 1998; Stokes, MacDonald, & Ridgeway, 2008). Given the large amounts of public dollars spent on these projects, do the benefits justify the costs? There are two sub-questions implied in this question. 1) What are the potential benefits of urban rail transit systems? 2) Are urban rail transit investments more cost-effective compared to the alternative public transit mode—buses?

1) A synthesis of the potential benefits of urban rail transit

Previous studies have summarized the potential benefits of having an urban rail transit system into three sets (Litman, 2012): environmental benefits, economic benefits and social benefits, as Figure 2 illustrates.

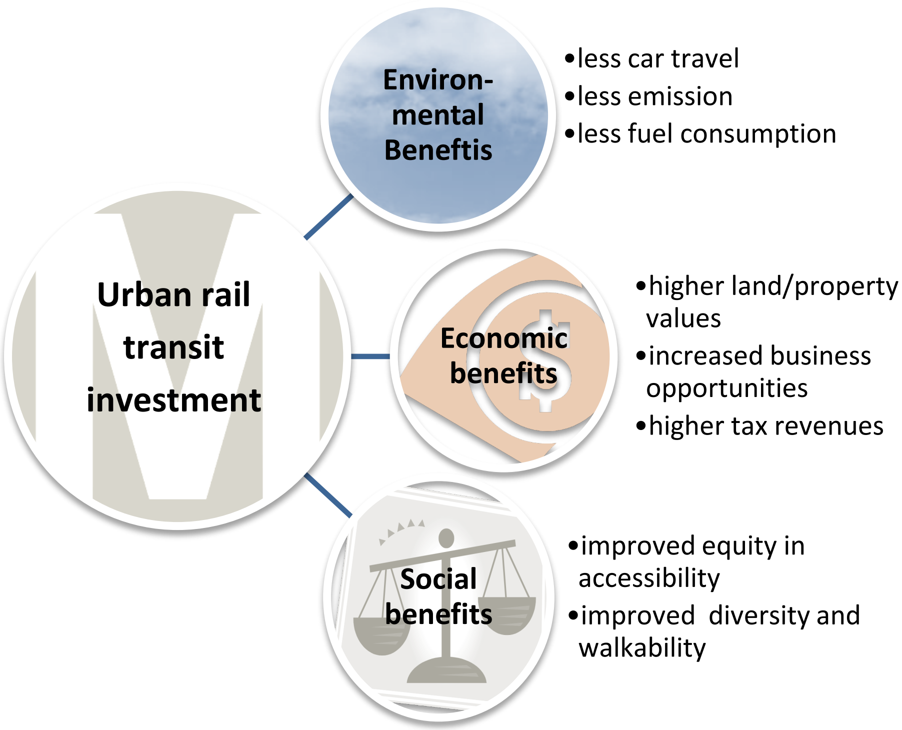


Figure 2: The potential benefits of urban rail transit investments

The potential environmental benefits of an urban rail transit system include reduced car travel, reduced green-house gas emissions, reduced air pollution, and reduced fuel consumption (Shapiro, Hassett, & Arnold, 2002). These benefits are solely dependent on the expectation that introducing an alternative travel mode will reduce the amount of travel by automobile. Chapter 2 provides a review of the empirical evidence on this point.

The economic benefits that an urban rail transit system may bring include increased land values, increased business opportunities in the station area, and increased tax revenues from the expected increase in property and business taxes (Bhatta & Drennan, 2003). These benefits come from the increased location advantage due to the increased accessibility of the station area. Whether these economic benefits can be realized depend on whether the desired development can happen in the station area. In other words, only the "highest and best use" (Alonso, 1964) of the land will yield the highest land rent and the highest taxes.

Lastly, introducing a new urban rail transit line may cause some indirect social benefits—improved social equity and neighborhood livability. For the transit-dependent people, urban rail transit has the potential to provide more access to opportunities than is possible by bus alone. This will increase their accessibility not only to necessary services but may also increase their employment opportunities (Bollinger & Ihlanfeldt, 1997; Cervero, Sandoval, & Landis, 2002; Douglas, 2010; M. Garrett & Taylor, 1999; Lewis-Workman & Brod, 1997; Ong & Houston, 2002; Sanchez, Shen, & Peng, 2004; Winston & Maheshri, 2007). Urban rail transit may also transform the physical characteristics of the neighborhoods: a rail station can become a local focal point that attracts people and businesses (Douglas, 2010). If well-designed compact developments happen, the station area could become a dynamic place with improved diversity, walkability, inter-personal interactions, and a stronger sense of community (Besser & Dannenberg, 2005; Brown & Werner, 2007; Lachapelle & Noland, 2012; MacDonald, Stokes, Cohen, Kofner, & Ridgeway, 2010; Stokes, et al., 2008). In the long run, the improved walkability of the station area could promote a healthier life style among the local residents with more physical activities (Besser & Dannenberg, 2005; Brown & Werner, 2007; Lachapelle & Noland, 2012; MacDonald, et al., 2010; Stokes, et al., 2008).

2) Making impacts on land use change: the key advantage of rail compared to bus

Not all the benefits mentioned above are unique to rail transit only. Another widely used mode of public transportation, bus transit, can also achieve some of the environmental benefits of a rail transit system. As long as buses serve riders who would otherwise travel by automobile, these buses are contributing to the reduction of car travel, as well as the accompanied gas consumption, green-house gas emissions, and air pollution. If we use the number of passenger miles by transit as an approximate indicator of the environmental benefits associated with public transit systems, we can easily compare the cost-effectiveness of rail versus bus (with regard to environmental benefits only). As Table 1 shows, the average cost per passenger mile is almost the same for bus and rail transit. In other words, there is no clear winner between the two in terms of environmental benefits.

Table 1: Comparison of transit cost by mode in the U.S., Year 2010

Measures	Bus	Urban Rail
Passenger miles, millions	21,013.0	18,580.0
Capital cost, million dollars	4,513.4	8,920.6
Operating cost, million dollars	18,831.4	11,556.9
Total cost, million dollars	**23,344.8**	**20,477.5**
Average cost per passenger mile, dollars	1.11	1.10

Data source: 2012 APTA Fact Book, Table 22, Table 23

However, it is very rare to observe substantial economic and/or social benefits of a bus system. In most cases, rail transit has an overwhelming advantage over bus transit in terms of affecting the density and development pattern of the neighborhood in proximity. The key distinction between the two public transit modes, rail and bus, is the attachment to a fixed location. Compared to bus, urban rail transit systems are more likely to stimulate development effects in the neighborhood, because they represent substantial investments in fixed locations (Black & Lane, 2012). With fixed tracks and well-established station structures, it is not easy to change the route of rail transit systems. Therefore, both residents and developers can be confident that rail transit service will remain in place for a long period of time. Fixed rail transit facilities provide the residents in the station area a promising expectation that they will have good transportation access as long as the station is there. Meanwhile, the long-term existence of the transit facility serves as an incentive for developers to invest in the land in the vicinity. By contrast, bus investment is usually not tied to certain locations, and bus stops and routes are subject to change, thus leaving much less incentive for developers to invest in land development along bus routes.

Given that the share of transit commuters has been continuously decreasing in most American cities (Baum-Snow & Kahn, 2005), the expected environmental benefits of public transit systems from diverting drivers off the road appear to be less prominent. Under this condition, the potential economic benefits and social benefits of urban rail transit systems seem more important than ever. In many other ways, bus could have a clear advantage over rail. It is the development effects expected from urban rail projects that make rail distinctive from bus. Therefore, gaining a better understanding of the impacts of urban rail transit on land-use development will offer new insights in the debate on the costs and benefits of urban rail transit investments.

1.5 Exploring urban rail transit projects' effects on density change

Although there is a rich and well developed literature on how land use patterns may affect the use of public transit (and rail transit in particular), evidence on the reverse link—how the investments on rail transit may affect land use and development is much less developed (Huang, 1996). For the last several decades, scholars attempted to test the development effects of transit facilities in many American cities with modern rail transit facilities. Their investigation on the development effects of urban rail projects covered many specific dimensions: density, diversity, design, to name a few, but ended up with mixed results (Atkinson-Palombo, 2010; Badoe & Miller, 2000; Black & Lane, 2012; Bollinger & Ihlanfeldt, 1997; Cervero, 1994a, 2004; Cervero & Landis, 1997; Dueker & Bianco, 1999; T. Garrett, 2004; Gatzlaff & Smith, 1993; Green & James, 1993; Hess & Lombardi, 2004; Huang, 1996; Knaap, Ding, & Hopkins, 2001; Lewis-Workman & Brod, 1997; Loukaitou-Sideris, 2010; Mackett & Edwards, 1998; Marshall, 2013; Sutherland, 2010; Weinstein & Clower, 2002).

These previous studies that focus on individual cities usually provide estimates on only one or two dimensions of the development effects of a single urban rail system, and they typically offer few insights into the mechanisms of such effects. Why do we observe development effects in some cases but not the others? Why do some rail lines generate larger effects than others? This dissertation aims to address questions like these by exploring not only the existence and magnitude of the development effects of urban rail transit systems, but also the mechanisms that influence such changes. To do so, it studies one specific dimension of the development effects: the change in densities.

In the planning field, density may be broadly defined as the number of units of interest per area, where such units could be residents, buildings, roads, or jobs. This research focuses on two types of density: population density (defined as persons per square miles) and housing density (defined as housing units per square miles). The investigations in this research are two-fold: 1) to estimate the effects of new urban rail lines on the changes in population and housing densities in nearby neighborhoods in each individual metropolitan area; 2) to explore the influences of exogenous factors on the population and housing densification impacts that a rail line can bring. To provide the most recent evidence on the densification effects of urban rail transit, this study chooses four metropolitan regions that built or expanded urban rail transit systems in the 1990s—Chicago, Denver, Los Angeles, and Washington, D.C. The different urban settings in these four regions offer several dimensions of variation that may illuminate the significance of project context on the densification effect of urban rail transit.

Summary of main argument and organization of dissertation

The global attention to sustainable development led to the resurgence of urban rail transit investments in the United States since the 1970s. The large amount of public dollars spent on the new urban rail lines stimulates hot debates on the costs and benefits of those projects. Quite often, investments on rail transit are evaluated against investments on bus transit in terms of their returns to investments. Scholars have revealed the potential benefits of urban rail transit systems from three perspectives: environmental benefits, economic benefits, and social benefits. Out of many aspects of the benefits that urban rail transit systems may bring, the land use effect is the key advantage of rail transit, compared to bus transit. However, previous attempts to evaluate the land use effects of various urban rail transit systems have yielded mixed results, which suggest that the presence of such land use effects are conditional on other exogenous factors. This research takes the challenge to explore what those exogenous factors are and to reveal the mechanisms of how these factors interfere with the land use impacts of urban rail transit. In particular, it focuses on the density dimension of land use forms and studies the population and housing density changes in the neighborhoods served by several new rail lines opened in four U.S. metropolitan areas in the 1990s.

The structure of this dissertation is organized as follows. Following the introduction chapter, Chapter 2 reviews the literature on the transportation and land use connection debate, with a focus on the development impacts of urban rail transit projects. Based on the literature review, Chapter 3 presents a conceptual framework that explains the mechanisms of the densification effects of urban rail transit systems and raises the research questions and hypotheses, raises the specific research questions and explains the methodology of the research. Next, Chapters 4 briefly describes the urban rail transit development history and the land use conditions in the four case regions. Chapter 5 discusses the findings from spatial analysis on the pattern of the density change in the four case regions. Chapter 6 reports the results from the regression analysis of estimating the densification effects and evaluating the influences of the neighborhood factors on densification effects. Based on the results from Chapter 6, Chapter 7 attempts to define and examine the station typology and experiments with how to use station typology information to predict densification outcomes. Finally, Chapter 8 concludes the whole study and makes a statement on its policy implications.

Chapter 2: Literature review: rail transit, project context, and density change

This chapter reviews two main bodies of literature upon which this dissertation research is built. The first body of literature discusses the impacts of density on transit use, which is related to why densification effects are worth discussing. The second body of literature explores the reverse causal link—the development effects of urban rail transit systems. In particular, the review focuses on summarizing the exogenous factors that are found to have influences on the development effects. The mixed findings of those studies show the necessity of carrying out this research; the methods used in those studies are inspiring to the research design of this study. Because of the focus of this research is on the investments on modern urban rail transit systems in the United States, the studies reviewed here are focused on North American cities.

2.1 The impacts of density on urban rail transit systems

In her seminal book *"The Death and Life of Great American Cities",* Jane Jacobs (1961) pointed out that sufficient population density was one of the four indispensable conditions to generate exuberant diversity in a city. During a few decades of discussion on compact cities that followed, however, the claimed impacts of a dense urban form have gone far beyond creating diversity. Since the mid-20th century, a large number of researchers studied how dense urban forms may affect transportation outcomes. Among all those studies, two groups shed light on the influences of density on transit use: 1) studies on how density affects the travel behaviors of residents—dense urban forms may reduce car travel and promote transit use; 2) studies on how density affects the feasibility of transit systems—dense urban forms may promote high transit ridership. The major findings from these studies are summarized in this section.

1) Evidence on higher density and reduced car travel

The rationale behind many pro-density planning recommendations is an assumed relationship between higher density and less car travel and energy consumption. In one of the early and seminal works on this topic, Newman and Kenworthy (1989), based on a study of a global sample of 32 cities, concluded that high-density cities consume less energy. They also contributed less energy consumption in dense cities to less auto dependence. Although the causality of such relationship is debatable, the strong correlation between low density and high energy consumption receives wide support. For example, a later study by Dunphy and Fisher (1996) also found a general tendency for less car driving in higher-density metropolitan regions. Although their analysis was drawn based on simple one-way cross-tabulations and plots, the result suggested a negative correlation between density and motorized travel on the metropolitan level, regardless of all other interferences. Many other researchers conducted similar studies and found that the reduction in gas consumption in dense metropolitan areas was presumably due to the reduction in car travel in dense urban settings (Badoe & Miller, 2000; Cervero, 1994b; Cervero & Kockelman, 1997; Dueker & Bianco, 1999; Dunphy & Fisher, 1996; Ewing, 1995; Handy, Cao, & Mokhtarian, 2005; Schimek, 1996a; Smith, 1984).

As the most recent evidence on this topic, a recent study on the 50 largest metropolitan areas in the United states by Levine et al. (2012) showed that a negative correlation between urban density and the amount of motorized travel prevailed, as Figure 3 illustrates.

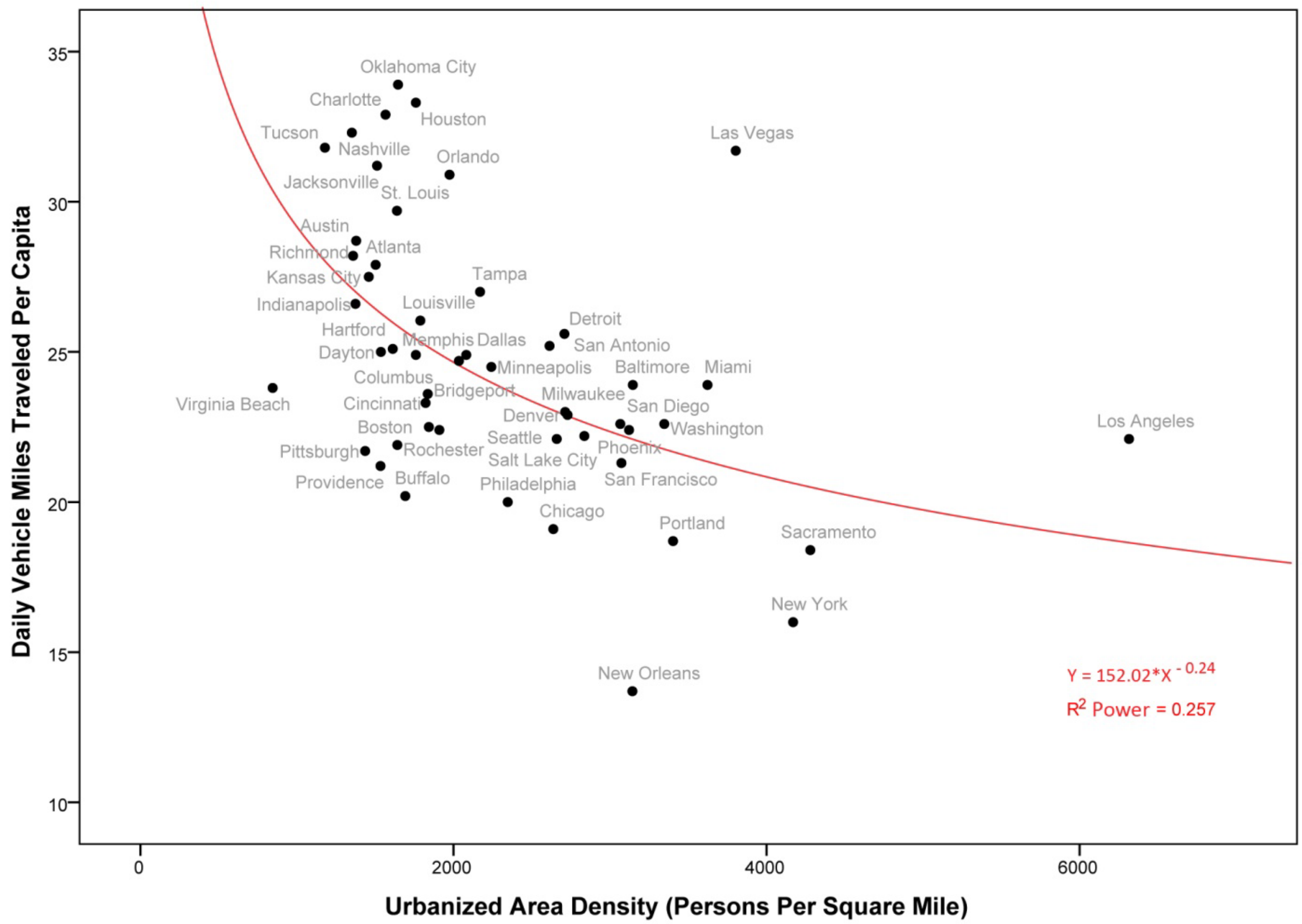


Figure 3: Daily vehicle miles traveled and urban density of the 50 largest urbanized areas in U.S., 2008
(Reprint of Figure 8 in Levine et al. 2012)

These few studies mentioned above focused on metropolitan/city level only. Similar evidence was also found in many other studies which focused on the neighborhood level. Using the 1990 Nationwide Personal Transportation Survey, Schimek (1996a) found a negative correlation between neighborhood density and the amount of car travel of residents. The estimated impact was marginal, though: doubling the population density of a zip code area only led to about seven percent reduction in households' vehicle miles traveled. Cervero and Kockelman (1997) used the data from 1990 travel diary survey in Bay Area and studied how the three dimensions of land use—density, diversity, and design—affected the travel behaviors of residents. Their findings suggested that neighborhood density, among other factors, did reduce trip rates and encourage the use of non-auto travel modes. Some other studies found regional accessibility and proximity to jobs and other attractions would reduce vehicle miles traveled (VMT) per person (Ewing, 1995; Ewing & Cervero, 2001; Kockelman, 1997). By their definition, measures of regional accessibility, as the weighted sum of opportunities at destination, have already accounted for the density element. In fact, as recent studies revealed, high density is the key to high accessibility (Grengs, Levine, Shen, & Shen, 2010; Levine, et al., 2012). Therefore, it is very possible that density works through accessibility to affect the amount of car travel.

Though most of these studies reviewed above only yielded correlation inferences, a few recent studies began to find evidence on the causality of density of reduced car use as well. Handy et al. (2005) designed a quasi-longitudinal study to investigate the relationship between the change in neighborhood characteristics and that in travel behaviors in Northern California. Their results did support a causal relationship between density and less car travel: an increase in density of groceries, pharmacies, and theaters around the neighborhood contributed to some decrease in driving. Another recent study in Germany also confirmed the causality of density on reduced car use by introducing instrumental variables in their model (Vance & Hedel, 2007). Their study showed that both commercial density and street density would place a negative impact on car use and distance traveled by car.

2) The relationship between reduced car travel and increased transit use

The literature on the relationship between density and reduced car travel, as reviewed above, is closely connected to an essential topic related to this dissertation research: the correlation between density and transit use. Reduced car travel does not necessarily lead to increased transit use in all cases, but the following text will explain how and why reduced car travel can bring increased transit use.

We may use an economic model to explain the mechanisms of reduced car travel associated with higher density. There are three possible explanations to the positive influence density has on abating the amount of car travel, which is illustrated by the dynamics of the demand of car travel in a simplified chart in Figure 4.

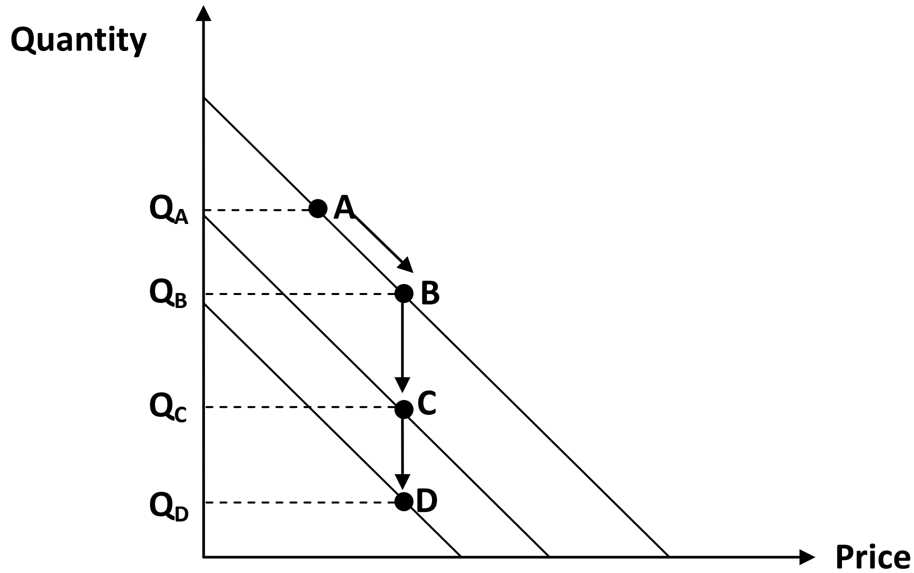


Figure 4: The economic mechanism of reduced car travel associated with higher density

Assume that the original quantity (Q_A) of car travel in an area is determined by the price of travel and the demand curve. An increase in density would affect the quantity of car travel in three ways.

First, as the density of urban development increases, the cost of car travel per mile becomes higher due to higher possibility of congestion and less availability of cheap parking (Schimek, 1996a). Therefore, people tend to drive less to offset that increased per-mile cost, so the quantity of car travel now decreases to Q_B. But the demand curve does not change its position.

Second, as the density of urban development increases, more destinations (jobs, grocery stores, restaurants, etc.) are available in the area, namely, the accessibility becomes higher (Levine, et al., 2012). As a result, people have less demand in car travel as they can reach their destinations with less travel. In this case, the demand curve shifts downwards and the quantity of car travel now decreases from Q_B to Qc.

Lastly, as the density of urban development increases, it becomes more feasible to develop and sustain a public transit system (Institute for Metropolitan Studies, 1994), thus allowing for a good alternative mode to car travel. As some motorized trips are made by transit instead, the demand curve of car travel shifts downwards again, and the amount of car travel is further reduced from Q_C to Q_D. It is this last part of change in car travel that is directly related to increased transit use.

3) Evidence on higher density and increased transit use

Besides the fact that density may cause driving to be more costly and encourage people to shift to other alternative modes, density also has a direct impact on rail transit use. In theory, rail transit projects need sufficient density to attract or increase ridership. The 2009 data collected from the 50 largest metropolitan areas in the U.S. showed a positive correlation between metropolitan population density and the share of passenger miles traveled by transit (Texas Transportation Institute, 2010). In practice, higher levels of transit service are usually provided in higher-density areas. This is attributable to the economy of scale from the concentration of residences in dense neighborhoods (Schimek, 1996a).

Scholars have found ample empirical evidence that showed rail transit projects would be more likely to have high ridership in densely populated and centralized cities (Baum-Snow & Kahn, 2005). An early but still widely cited book by Pushkarev and Zupan (1977) comprehensively investigated the relationship between density and transit use. They not only found positive correlation between urban density and the share of transit travel, but also developed several theoretical tools that would help predict transit use—residential density was one of the determinants. A later study of six U.S. metropolitan areas by Smith (1984) also confirmed the significant influence of residential density on transit use. Using time-series data, Schimek (1996b) compared the trend of transit patronage in Toronto to that in Boston and found that higher residential density was one of the reasons why Toronto's transit system attracted more riders over time. The importance of employment density was less studied than that of residential density, but scholars did find some supporting evidence that higher employment density promoted the use of alternative modes, including transit (Cervero, 1989). The magnitude of the impacts of density on transit use also varies from one place to another. As a recent summary of the related literature, Ewing and Cervero (2010) examined ten studies since 2001 and calculated that the average elasticity of transit use to residential density is 0.07. In other words, doubling residential density would be expected to lead to a 7% increase in transit use.

The mechanism of density's influence on transit use seems straightforward. On one hand, higher residential density around station-area neighborhoods brings more potential transit patronage. Without enough density and concentration of population, fixed rail transit can hardly receive a considerable amount of riders within a reasonable spatial range. On the other hand, higher employment density near transit stations means more commute destinations in proximity to transit, which may likely attract more commuters to use transit (Cervero, 1994b). Besides, the analysis on the mechanisms of how density can constrain car use (Figure 4) suggests that more people would switch from car to transit in dense areas where driving and parking costs are both high.

Compared to the widely accepted argument on the impacts of density on promoting ridership, maybe a more debatable topic is: what is the density threshold that could sustain a viable transit system? Transit agencies typically use planning criteria that recommend a minimum of seven dwelling units per acre to support basic bus service (Dittmar & Ohland, 2004). Densities lower than seven dwellings per acre produce little use of public transportation; densities in the range between seven to thirty dwellings per acre would yield dramatic increase in transit use as well as a sharp reduction in car travel (Pushkarev & Zupan, 1977). Another study found that a substantial increase in transit use occurs at a minimum of ten dwelling units per acre (Institute for Metropolitan Studies, 1994). Unfortunately, these density criteria are applicable to public transit in general, including both bus and rail. Rail transit typically requires higher densities than bus transit to produce enough ridership to offset the higher costs of rail over bus.

2.2 The development effects of rail transit investments

Compared to the prolific literature on estimating the impact of density on transit use, fewer studies looked into the reverse link—the impact of transit projects on density. Since the last few decades in the 20th century, planners have expressed increased interests in directing growth around rail transit stations, with the hope that it can curb the metropolitan areas from being more auto-dependent and decentralized (Huang, 1996). However, development does not automatically follow the construction of rail transit facilities, and the land use effects of rail transit are not as straightforward as one may expect. This section first reviews the theories behind the land use impacts of rail transit projects and then continues on summarizing the findings from previous studies that offered either direct or indirect evidence on the effects of rail transit on density change. It pays special attention to the two issues in the empirical studies: the exogenous factors that affect the land use effects and the methodology used to evaluate the land use effects.

1) Theories behind the land use impacts from rail transit

Location theory (Alonso, 1964) provides the basis for expecting that transit investments may cause land use changes and development effects. In the original formulation of the location theory, a city is assumed to be a mono-centric place where all employment is located in the center. Under this assumption, land rents tend to be higher at locations closer to city center, because people are willing to pay more for land in exchange for savings on transportation. As landowners always seek “the highest and best use” of their land to offset the high land prices, the land at more central locations would be built more densely so that the land cost per unit can be lower. Consequently, the development at the center will be of the highest density and the density gradually declines as the distance from city center increases.

Although the spatial forms of some modern metropolitan areas have deviated from the mono-centric pattern, the principles of the location theory still apply, in a broader sense—land rents tend to be higher where accessibility to employment and other destinations is better, regardless of whether the employment are centralized or not. Therefore, an improvement on the accessibility of a location should result in an increase in the value of the land and an increase in the density.

If we assume that opening a new urban rail transit station at a certain location increases the accessibility of this location, having a new rail station will increase the relative location advantage of the surrounding neighborhoods compared to before, and the increased location advantage will lead to increased desirability and values of the land. As a result, residents and activities should shift towards the station area, making it denser than before. However, some scholars questioned the accessibility benefits of rail transit by arguing that “modern urban transit systems rarely, if ever, provide a major effective increase in accessibility, because the areas served tend to be already more accessible by auto.” (Knight & Trygg, 1977) Their argument has some merits in that accessibility by auto is usually higher than accessibility by transit due to higher travel speeds. Therefore, having a new rail transit system probably will not increase the accessibility of the station-area neighborhoods in general. Still, it is very likely that having a new rail transit station increases the accessibility *by transit* of the nearby neighborhoods. In other words, for people who travel by transit, a neighborhood with a new rail transit station definitely has an increased location value than before, and the neighborhood will grow denser when these people move into the area.

To sum up, the classic location theory provides a basis for our hypothesis that a new rail transit project may cause land use changes in the surrounding neighborhoods by activating a chain of effects—improving the location advantage, increasing the land value, and as a result, increasing the density. However, whether these effects will take place in reality is subject to examination. In the following, we will review the empirical studies that attempt to test whether actual modern rail transit projects in North American cities have caused land value increase and density increase or not.

2) Empirical evidence on the land use impacts of rail transit

Both land value increase and density increase are part of the expected land use impacts that rail transit projects make on the surrounding neighborhoods. Although this research will only focus on the density change caused by rail transit, it is also worthwhile to review the studies on the impacts of rail transit on land values, since they provide indirect evidence on the potential densification effect of rail transit. In one way, higher land values near transit stations suggest a potential demand for higher-density development to offset the land cost per unit, which means that an increase in density is likely to follow. In another way, increased property values are likely to be consequences of increased housing demand by increased population in the area. Either way, findings on rail transit's impact on property values could be considered as evidence of potential densification effect.

Urban rail transit systems may influence the property values in nearby neighborhoods by making two effects. On the positive side, being close to an urban rail transit stations can increase land values due to better accessibility and higher location advantage (Alonso, 1964)—the accessibility effect. On the negative side, being close to a rail line may decrease property values due to unpleasant noise and vibration (Hess & Almeida, 2007)—the nuisance effect. A majority of the empirical evidence showed that the accessibility effect would offset or even outweigh the nuisance effect, thus yielding positive net effect on the values of the properties located close to rail stations (Armstrong & Rodriguez, 2006; Bowes & Ihlanfeldt, 2001; Gatzlaff & Smith, 1993; Hess & Almeida, 2007; Landis, Cervero, & Guhathukurta, 1995; Lewis-Workman & Brod, 1997; Parsons Brinckerhoff, 2001; Weinstein & Clower, 2002). However, for properties near transit corridors but not close to any station, the nuisance effect became dominant, generating negative effect on their values (Armstrong, 1994; Armstrong & Rodriguez, 2006; Landis, et al., 1995).

Compared to the mostly confirmative evidence on the effects of urban rail transit on increasing property values, the direct evidence on the impact of rail transit systems on density change is less prominent. In the past few decades, a number of evaluation studies of modern urban rail transit systems used pre-post test methods to investigate the density change caused by rail projects in North American cities (Bollinger & Ihlanfeldt, 1997; Cervero, 1994a; Douglas, 2010; Dueker & Bianco, 1999; T. Garrett, 2004; Green & James, 1993; Hess & Almeida, 2007; Knight & Trygg, 1977; Landis, et al., 1995; Lewis-Workman & Brod, 1997; Litman, 2012; P. Nelson, et al., 2007; Parsons Brinckerhoff, 2001; Schimek, 1996b; Weinstein & Clower, 2002). Despite that almost every major urban rail transit system has been studied, findings from those studies are mixed and inconsistent. The presence, magnitude, and range of the impact all seem to vary from one case to another, even from one station area to another within the same city.

Some studies confirmed that urban rail transit systems increased density around stations or corridors in some cities, such as Boston, Montreal, Philadelphia, Toronto, and Washington, D.C. For example, Knight and Trygg (1977) surveyed the land use impacts of a few rail transit systems and found increased urban development induced around the transit corridor in Toronto and in Downtown Montreal. In the same study, it is found that the Lindenwold high-speed line in Philadelphia stimulated development of new suburban offices and apartment development nearby. However, this was later challenged as not convincing because the growth rate of new development in other parts of Philadelphia was equal or even greater during the same period (Badoe & Miller, 2000). Green and James (1993) thoroughly investigated the land use impacts of the rapid transit system (METRO) in Washington, D.C. between 1972 to 1980. They found that areas near METRO lines and stations experienced higher rates of employment growth than other parts of the region, especially for the employment in the service sector. Boston also experienced dramatic growth around its stations on Red Line, where more than one million square feet of office space was constructed from 1978 to 1986. Some scholars questioned the role of transit in this case and argued that such development would happen anyway because of the zoning change in the area (Huang, 1996). Yet it is very likely that the zoning change would not happen if there were not new rail transit lines constructed. To this end, it is the rail transit project that indirectly increased development density through promoting zoning changes in the area.

Some other cities such as Atlanta, Chicago, and Cleveland experienced little or even negative change in the neighborhood density around rail transit stations. According to the research by Knight and Trygg (1977), improvements to the rail transit system in Chicago did not generate any development impact. They argued that the high land costs and an already well-developed downtown district might explain such a phenomenon. In another case, Allen (1986) studied Cleveland's rapid transit line and found it not effective at all in attracting development. He attributed the absence of induced development principally to its design: the line passed through low-density industrial areas and was built entirely on a railroad right-of-way, where steep embankments isolated the line from adjacent land. Similar evidence was found in a study on Atlanta's MARTA (Bollinger & Ihlanfeldt, 1997), which showed that the density of population and employment in station areas were not affected much by the transit system, but the composition of employment shifted more towards the public sector in areas with high levels of commercial activity. Another study on MARTA reported that the population decreased by more than 11 percent within one-half mile from MARTA stations, although the employment increased by 13 percent within the same range (A. C. Nelson, Sanchez, Ross, & Meyer, 1997).

Even in the same transit system in the same city, researchers have found that extensive development may occur near some stations but not others. For instance, a research report on the performance of the Washington Metro showed that most new office development around transit stations were concentrated near seven of the eighty-one stations, while seventeen other stations experienced no such development at all (Metropolitan Washington Council of Governments, 1991). The report did not address why developers picked certain station sites or how the Metro played a role in their development decisions. Therefore, the observed dramatic variation in new development around Metro stations was still a myth. Another study on the Bay Area Rapid Transit (Cervero & Landis, 1997) also observed large variation among different stations. By looking into the land use change in twenty years following the BART service started, they found that new development was limited to Downtown San Francisco and Oakland, as well as a few suburban stations. They argued that the reason why other stations experienced very few land use changes was the neighborhood opposition or a weak real estate market.

To sum up, the empirical evidence on the land use impacts of urban rail transit in North American cities is mixed. In most cases, the accessibility effect brought by a new rail station can offset or even outweigh the nuisance effect. Therefore, a majority of the studies confirmed that having a new urban rail transit station did increase the property values in surrounding neighborhoods. However, whether such impacts on land values are accompanied by increases in development densities is not clear. Different studies on different rail transit systems in different cities yield dramatically different results. Even the same system in the same city can cause different density effects in different neighborhoods. Considering the complication of the urban development process, in which many factors and stakeholders would intervene, it is not surprising to see such mixed and conflicting findings on the densification effect of transit. Yet what are the factors that actually interfere with the densification effects of urban rail transit, then? The following review is a brief on the previous studies regarding this topic. Although most of them are speculative hypotheses without systematic analysis, these ideas are inspiring to this research.

3) The factors that affect the land use impacts of rail transit

Different scholars attempt to explain the variation in the land use effects of urban rail transit from different perspectives. All the arguments can be grouped into two categories: making hypotheses on the external factors, i.e., the barriers to neighborhood density increase following an urban rail transit development; and 2) testing the internal factors, i.e. the transit-related features that can influence the magnitude of land use impacts caused by rail transit.

The external factors include travel behavior, real estate market conditions, land use policies, and neighborhood conditions. First, some scholars argue that the location advantage brought by rail transit is very minimal, because driving has been the dominant travel mode in almost all contemporary cities in the United States. In this context, the role of rail transit was very marginal to the transportation system, thus the impacts of modern urban rail projects on accessibility improvement were very limited (Cervero & Kockelman, 1997; Giuliano, 1995). As a result, we will not observe significant increase in neighborhood value or density. Second, whether new development could happen largely depends on the condition of the real estate market. If the market is too weak, a new rail station built around that time will not make much development effects (Landis, et al., 1995). Thirdly, land use regulations can become one of the barriers that prevent densification. For example, higher density will not happen in the areas zoned to be low-density. Similarly, in areas where land ownership and development regulations are complicated, assembling land could be a difficult and costly task. In that case, it is also not easy to see densification happen (Cervero, 2004; Luscher, 1995). Lastly, neighborhoods around rail stations are the soil of the seed for densification. The conditions of the soil determine whether the seed can thrive. Many aspects of neighborhood conditions may affect the land use impacts of urban rail transit, including income level, demographic features, and the residents' attitude towards density.

Perhaps the most frequently mentioned aspect in previous studies is the income level of the station-area neighborhood. For example, Hess and Almeida (2007) conducted a study in Buffalo, New York and found that rail transit stations increased the values of nearby properties in high-income areas but decreased property values in low-income areas. However, such findings are just opposite to what Nelson (1992) found in Atlanta, where elevated rail transit stations increased home values in lower-income neighborhoods but decreased home values in higher-income neighborhoods. Findings on Miami Metro Rail by Gatzlaff and Smith (1993) suggested a third scenario—among all the neighborhood near rail transit stations, property values in high-income neighborhoods increased moderately while those in low-income neighborhoods were unaffected. Evidence from Los Angeles (Loukaitou-Sideris, 2010) finds a middle path—the development effects would not be realized in neighborhoods that are very wealthy or very poor. Rather, the neighborhoods with the moderate-to-middle income level enjoy the densification effects from urban rail transit the most. Again, all these different findings show that the land use effects of urban rail transit is highly sensitive to contexts. Residents' attitude against density is another important aspect of neighborhood conditions that may hinder the rail transit from causing density increase in the surrounding neighborhoods. As is documented in several research(Kent, 1997; Parsons Brinckerhoff & Quade and Douglas, 1996), in places where a neighborhood's opposition to densification was strong, it would be very unlikely to observe development effects of urban rail transit projects.

The internal factors are mainly regarding the types of the transit systems and the types of the stations. Due to higher speeds and better access, rapid heavy rail systems tend to have a greater land use impact on nearby neighborhoods than light rail (Parsons Brinckerhoff, 2001). As introduced in the first chapter, the different characteristics of the two types of urban rail transit determine that heavy rail has a larger passenger capacity and travels faster than light rail does. In that sense, heavy rail investments could increase the accessibility and the location advantage of a station area by a greater magnitude than light rail does, thus causing a larger densification impact than light rail could. However, that is not always the case in practice. A comparative study on two urban rail transit systems in California—the San Francisco BART heavy rail and the San Diego Trolley light rail shows that they both impose similar strong impacts on land value increases due to “equally high quality of service” (Landis, et al., 1995) As for the influence on the station types on the land use effects of urban rail transit, the only systematic study was conducted on the Atlanta rail system MARTA (Bollinger & Ihlanfeldt, 1997). In that study, the authors categorized all the stations into five types: high-density urban node, mixed-use regional node, commuter station, commuter center, and neighborhood station. Their findings showed that densification effects only took place in the second type— stations that are mixed-use regional node. Maybe one explanation is that these areas had already experienced some progressive planning/development before the rail transit was introduced and were more prone to densification.

To sum up, previous studies proposed several possible factors that may influence the land use impacts of rail transit projects. External factors include the general trend in travel behaviors, real estate market conditions, land use policies and neighborhood conditions. Internal factors include transit types and station types. Unfortunately, most of the scholars who proposed these factors only did qualitative studies or make simple speculative statements, without conducting systematic analysis or empirical testing. For a few studies that did test certain factors using empirical data, the findings were, again, inconsistent from one city to another. Despite the inconsistency in these findings, they all remind us of the importance of the contextual factors of rail transit projects when evaluating the impact of transit.

4) The geographic extent of the impacts of urban rail transit

In the studies that evaluated the development impacts of urban rail transit systems, a key decision to make is the definition of the “impact range”. An impact range is a geographic extent to which the effects of an urban rail transit facility take place. Beyond the impact range, the effects are negligible. Unfortunately, there is no one solid theory that guides the scholars to make such a decision. Therefore, there is no consistent cut-off distance used in all the studies reviewed above that evaluated the impacts of urban rail transit systems. Selected distance rings varied from within 1000 feet from the station to about 3 miles from the station. For example, Anas (1979) simulated the effects of the Midway Line in Chicago on the housing market and found that the effects on housing rent became negligible beyond 1.5 miles from the stations.

Lewis-Workman and Brod (1997) found that property values increased within a one-half to one mile buffer zone from the rail stations in Portland, Oregon. Findings on the Metro Link of St Louis by Garrett (2004) also showed that the value-added benefits on properties disappeared at around one-mile distance from stations. However, Bowes and Ihlanfeldt (2001) examined the MARTA system in Atlanta and found that its positive influence on property values reached as far as three miles from the stations. All these findings suggested possible spatial boundaries of the impacts from rail transit, which will help with the identification of treatment and control groups in the research design of this study. The table below summarizes the impact ranges used in the previous studies that provide direct or indirect evidence on the densification effects of urban rail transit projects in North American cities.

Table 2: A review of the impact ranges used in evaluating the impacts of urban rail transit

City (Rail system)	Study	Impact range (distance from station)	Findings
Atlanta, GA (MARTA)	(Bollinger & Ihlanfeldt, 1997)	within 1/4 mile	No effect found on employment or population densification
Buffalo, NY (Metro Rail)	(Hess & Almeida, 2007)	within 1/4 mile	Home price has a premium of $1300–3000.
Cleveland, OH	(Knight & Trygg, 1977)	within about 1/4 mile to 1/3 mile	Very little evidence of transit-related development found.
Dallas, TX (DART)	(Clower & Weinstein, 2002)	within 1/4 mile	Property value increased 32% near DART stations compared with 20 % in control group areas.
Los Angeles, CA (Blue and Gold Lines)	(Loukaitou-Sideris, 2010)	within 1/4 mile and 1/2 mile	The Blue Lines did not stimulate much new development while the Gold Line did.
Philadelphia, PA	(Gannon & Dear, 1975)	within about 1/6 mile	Not much new development occurred due to rail transit.
Portland, OR (Eastside MAX)	(Lewis-Workman & Brod, 1997)	within 1/2 mile, 1 mile	Property value increased by $60-$100 for every 100 feet closer to a station.
Portland, OR (Eastside MAX)	(Dueker & Bianco, 1999)	within 1/4 mile	Multifamily housing development increased more rapidly near rail-station areas than elsewhere, but the build-out rate is lower when controlling for available multifamily land.
San Diego, CA (LRT)	(Gomez-Ibanez, 1985)	within walking distance	The trolley was an unimportant factor in development decisions.
San Diego, CA (LRT)	(Cervero & Duncan, 2002)	within 1/4 mile and 1/2 mile	Property value increased 10 per cent (East Line) to 17 per cent (South Line) for multi-family homes.
San Francisco, CA (BART)	(Webber, 1976)	within central district	Booming of office development after the system opened.
San Francisco, CA (BART)	(Landis, et al., 1995)	within 1 mile and 3 miles	Most new residential and commercial development happened within one to three miles.
San Francisco, CA (BART)	(Cervero & Landis, 1997)	within 1/4 mile and 1/2 mile	Only stations in Downtown San Francisco and Oakland experienced development effects nearby.
St Louis, MO (Metro Link)	(T. Garrett, 2004)	From 1/4 mile to 1 mile	Property value increased by 32% or $140 for every 10 feet closer to station.
Toronto, Canada	(Heenan, 1968)	within downtown near the transit system	Two-thirds of the new developments were attributable to the transit system.
Washington, D.C. (Metro)	(Cervero, 1994a)	within 1/4 mile	Office density increased in the station area.
Washington, D.C. (Metro)	(Green & James, 1993)	within 1/4 mile	Larger increase in employment density around the stations.

From the impact ranges listed in the table above, it seems that a-quarter mile and a-half mile from the stations are the most frequently used radii to define the impact range. Perhaps the most widely mentioned rationale behind such selections is the consideration of a walkable distance for most people (Besser & Dannenberg, 2005; Lachapelle & Noland, 2012). If an average adult walks at about two miles per hour, a quarter mile usually takes about ten minutes to walk and a half mile takes twenty minutes to walk, even the latter of which is a quite reasonable amount for the daily commuters who walk to the stations. Another less frequently cited reason is that the spacing between two urban rail stations is usually about half a mile to one mile (Vuchic, 2005). Therefore, depending on the actual spacing of stations on a transit line, using a-quarter or a-half mile as buffering radii around each station can avoid impact zone overlaps in most cases.

Summary of literature review

Density has the potential of affecting transit use for several reasons. On one hand, residents in areas of high density experience less amount of car travel because of increased costs of driving, improved accessibility and reduced travel needs, as well as a wider range of alternative travel options. On the other hand, density supports the feasibility of rail transit in that it brings more potential transit patronage within a certain range and attracts more transit trips to destinations in proximity to transit stations.

On the reverse side, urban rail transit may also make impacts on density. According to previous studies, there is strong evidence that proximity to transit stations causes increases in property values, which indirectly suggests an increased housing demand and a potential densification effect in station-area neighborhoods. As for the direct evidence on the density change caused by rail transit projects, however, the evidence is mixed and unclear. The classic location theory tells us that higher density could be expected around rail station areas due to increased accessibility benefits. Also, some researchers did find densification effects following the opening of new rail transit projects in some cities. However, urban rail projects do not always demonstrate densification effects. Previous evidence showed that the existence and magnitude of the densification effects vary across cities and neighborhoods. To explain such variance, scholars proposed several external and internal factors, including travel behavior, market conditions, neighborhood conditions, land use policies, as well as system types and station types. These factors become the candidates of the exogenous factors to be considered in the models of this study.

Given the significance of the development effects of urban rail transit in the broader debate on the cost-benefit issue of such investments, it is imperative to figure out what factors actually interfere with rail transit systems' development effects and to what extent do they make influence. Unfortunately, it has never been done in a systematic way before. Most early studies reviewed in the chapter used simple comparison between station areas and non-station areas. Straightforward as these comparisons may be, such a method fails to take into account other variables affecting development/land use changes and therefore is prone to omitted-variable bias. Some later studies controlled for other factors that may be relevant to development change in their analysis. However, they failed to estimate how those factors would influence the densification effects caused by urban rail transit. In other words, controlling for exogenous factors in the models can only yield estimates on how those factors may affect the density change, but such models did not reveal how the exogenous factors may interfere with rail transit's potential in affecting neighborhood density change. Only one study included interaction terms to reveal how the effect caused by rail transit may be interfered by exogenous factors, but it only included one factor-station types. It is worth noting that all the internal and external factors that may promote or prohibit the densification effects of urban rail transit are intertwined with each other. Any new rail transit system comes with a unique package of these conditions, thus it is difficult to estimate the effect of each single factor. This research will take the challenge and explore the relationship between exogenous factors and the densification effects of urban rail transit projects.

Chapter 3: Research design and methodology

This chapter explains the methodology used to carry out the task of finding evidence on how urban rail transit projects may affect density change, and how the densification effects of urban rail can be promoted or prohibited by neighborhood factors. It starts with laying out a conceptual framework that explains the mechanisms of the densification effects of urban rail transit. The following section describes specific research questions and the hypothesis of this study. The third section explains the selection of the case regions to be studied. The fourth section introduces the three analytical methods used to answer the research questions. The last section lists the data sources for the analysis taken in this study.

3.1 A conceptual framework: the mechanisms of how transit may drive densification

The densification effects of urban rail transit may happen through several intermediate steps, under different conditions. Based on the existing literature on transportation and land-use interactions, potential mechanisms of the densification effects of rail transit are illustrated in the flow chart (Figure 5). In this flow chart, black-bordered rectangular shapes indicate the possible processes following the introduction of a new rail transit project; black arrows indicate the causal links between the induced changes. The blue-bordered diamonds are the conditions that are needed in order to make the decisions along the process. Solid-colored rectangular shapes are the outcomes.

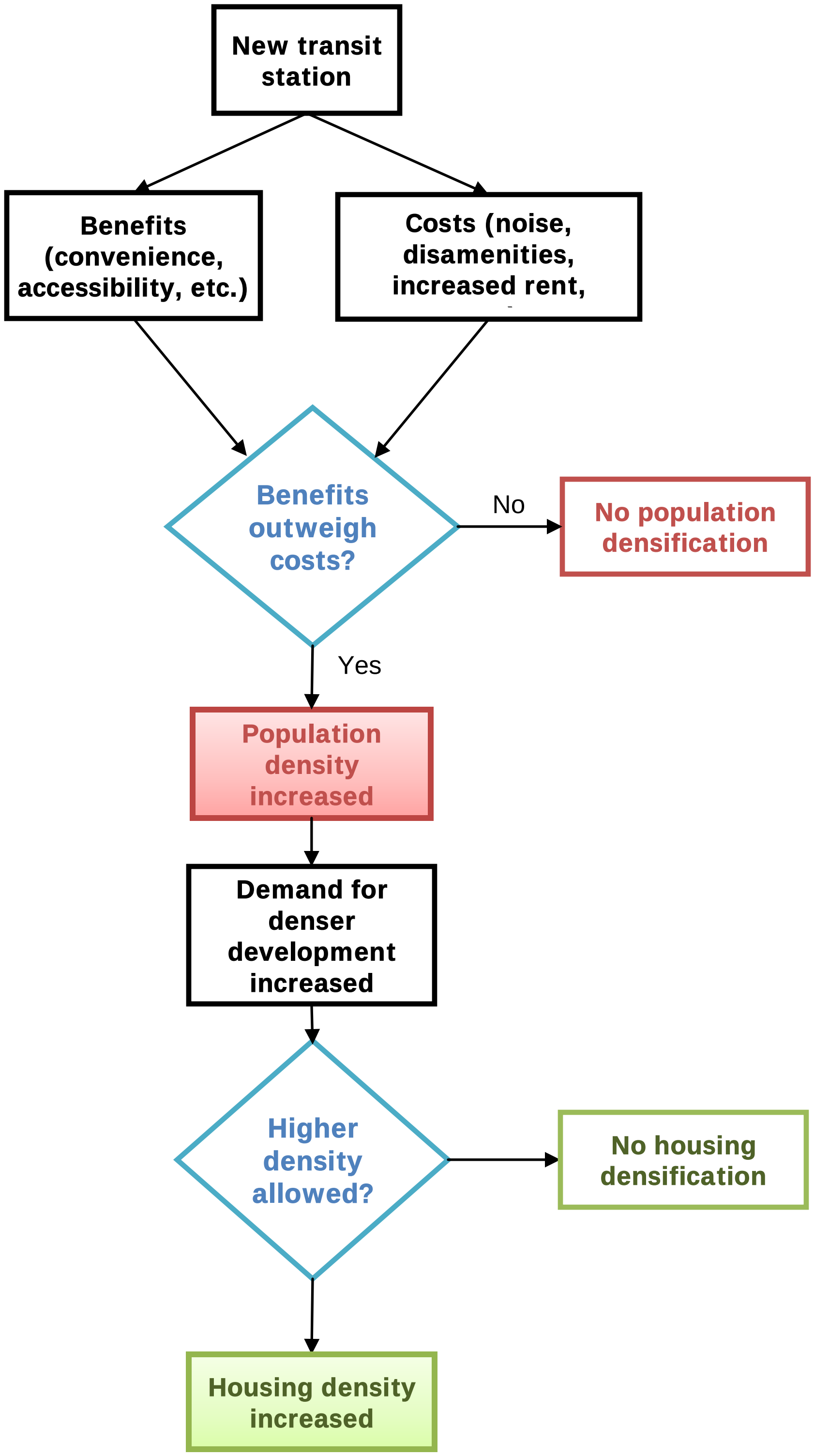


Figure 5: The diagram showing the mechanisms of the densification effect of urban rail transit

The opening of a new rail transit station brings both benefits and costs for every resident in the nearby neighborhood. On one hand, new rail station provides an affordable and fast transportation option that does not exist before and makes the place more accessible to other parts of the region. On the other hand, rail stations also have disamenities—noise from the train, obstruction in the view, and a likelihood of increased housing cost in proximity. For every potential resident in the neighborhood, the set of the benefits and the set of the costs brought by a new rail transit station are different. The residents would choose either to live in the neighborhood or to leave it, depending on whether the costs can be offset by the benefits. For certain groups of people, the improved transit accessibility is an attractive feature of the station-area neighborhood. These people would then self-select to stay in (or move to) these neighborhoods in order to enjoy the high transit accessibility and the convenience of transit travel in the area.

Two groups of people are candidates of such self-selection: people who are dependent on transit due to economic constraints and people who favor the transit travel mode for personal preferences. People who do not have the financial or physical ability to drive rely on the public transit system to meet their routine travel needs (Dukakis Center for Urban and Regional Policy, 2010). Therefore, their residential location choices are usually limited to places with good public transit service (Glaeser, Kahn, & Rappaport, 2008; Kain, 1968, 1992). With improved rail transit accessibility, station-area neighborhoods become particularly attractive to these transit-dependent people. Another group of people who are also attracted by rail transit prefer public transit and use it as their major travel mode by choice. These people would self-select themselves into communities that support their preferences. College students and young professionals are commonly found in this group (Kahn, 2007).

If the number of people who choose to live in the neighborhood is higher than the current number of residents, the population in the station area will increase. In other words, this new station will cause population densification. And when population densification happens in the neighborhood, the housing demand will increase accordingly. Meanwhile, developers would prefer to build more densely in the station area for economic reasons. This is because superior accessibility at the location near new rail transit stations brings economic advantages, generating premiums on land rent (Alonso, 1964). As a result, developers are inclined to build more densely in the area in order to offset the increased land cost.

Although the economic theories predict developers' interests in building densely in the station area, this does not ensure that housing densification can actually happen. In reality, the land in the best location with highest accessibility may not reach the highest density possible when regulatory barriers or other factors impede dense development. For a parcel with presence of a transit station in proximity, its land value is expected to be higher than without the station, but the added value would not be realized if profitable development is not allowed. For example, developers may find it more cost-effective to build a high-density mixed-use condo complex on the land, but such development would not be feasible if the land was zoned single-family housing and no zoning change was allowed. In that case, housing densification would not happen unless the regulatory barriers are removed (Levine, Inam, & Torng, 2005). The attitude of local residents is another determinant of whether the potential interests of dense development among developers can actually lead to densification in the area. Near a single-family neighborhood, the NIMBYism ("Not in My Back Yard") could become a very strong barrier towards dense development.

3.2 Research questions and hypotheses

Laying out the possible outcomes and the key elements in determination of densification effects in the flow chart above helps us to sort out the possible reasons why we would or would not observe the densification effects of an urban rail system. This study will then focus on factors that are related to different cities/system types/neighborhood types, and try to explain the difference in densification effects among them. The goal is to assess how factors promote or depress the densification effects of urban rail transit systems. The specific research questions this research attempts to answer are elaborated below.

Question (1): What are the population/housing density change outcomes in the neighborhoods near new rail transit stations in each case city? The densification of population and housing in the areas close to rail stations is one possible and considerable benefit of rail transit. The null hypothesis is that the density changes in the neighborhoods close to rail stations is to the same as the changes in other neighborhoods of similar types in the region. An expected result is that rail transit project does induce higher population and/or housing density around stations areas, so the densities of the neighborhoods near new stations grow faster than that of other neighborhoods.

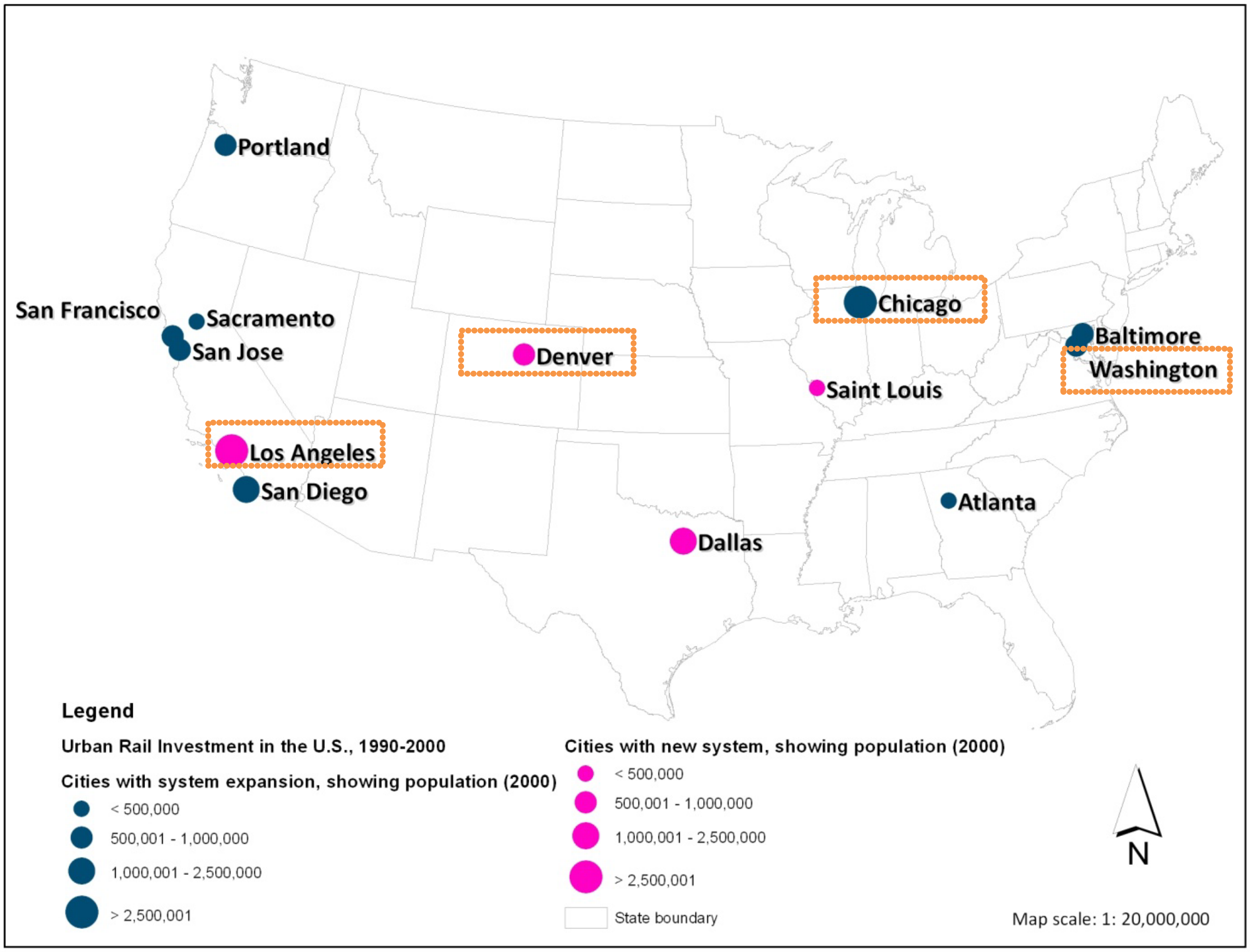
Question (2): What external factors affect the densification effects caused by urban rail transit stations? This question explores the interaction between the pre-project conditions of the neighborhoods and the densification effects of rail transit. Given the mixed findings from the past studies, even within the same city, different rail transit stations may impose quite different impacts on nearby neighborhoods. For example, the income level, racial composition of the existing residents, availability of vacant land, and zoning ordinances in the area may all affect the potential densification effects of a new rail transit station. Based on the literature reviewed in the previous chapter, the hypothesis on this question is that densification is more likely to happen in the neighborhoods which had healthy economic conditions and attractive geographic locations before the transit project was built, as well as less opposition to density among the residents.

Question (3): What internal factors affect the densification effects caused by urban rail transit stations? The working definition of urban rail transit in this research includes two different types of rail transit –heavy rail and light rail. Previous studies found mixed evidence on whether one type is more effective than the other in terms of making land use impacts. This research is also interested to see whether different types of systems actually cause density changes in the surrounding neighborhoods differently and how.

Question (4): Do the internal/external factors affect density at new rail stations differently among different metropolitan regions? As an addition to the previous question, this question looks into the inter-city variation in the densification effects to see whether there is consistency among different urban settings. The null hypothesis is that the transit impact is the same in all metropolitan areas, but previous studies suggest that we may expect large variations in the densification effects as well as the influences of the neighborhood factors across different case regions (Huang, 1996).

3.3 Case selection

To answer the questions listed above, this research selects several metropolitan regions in the United States as cases of study. The goal of this study is to provide the most recent evidence on the densification effects of urban rail transit in the United States. Therefore, the study regions are chosen from a list of American metropolitan regions that have expanded or newly built urban rail lines since 1990. Moreover, because the impacts of rail transit may not be present in a short period of time following the construction of the rail projects, this study excluded projects built after 2000 to allow for at least ten years after the projects opened so that the densification effects can be observed. These two criteria yielded thirteen cities as the potential candidates for the cases of this study. Map 1 on the next page shows the geographic location, the population size (by the size of the dots) of each case region, and the distinction between new systems and old systems (by the color of the dots).



Map 1: U.S. cities that invested in urban rail transit, 1990-2000

Among these thirteen cities, four built new urban rail systems from scratch during the 1990s. The rest nine cities constructed rail lines before 1990 and expanded their systems between 1990 and 2000. It would be ideal to study all these thirteen cases for a complete investigation into the densification effects of urban rail transit investment during that time. However, due to the time and budget constraints, this dissertation research could only choose a manageable sample out of them. To form a sample that represents different geographic locations, population sizes, and both new and old systems, four metropolitan regions are selected for this study: Chicago, Denver, Los Angeles, and Washington, D.C. Table 2 summarizes the key features of the urban rail transit investments between 1990 and 2000 in these four case regions.

Table 3 : New urban rail projects constructed during the 1990s in the case regions

Metropolitan Region	Rail Lines	Type	Miles	First Open Dates	Rail Transit before 1990
Chicago	Orange Line	Heavy Rail	9	1993	Yes
	Green Line	Heavy Rail	1	1994	
Denver	D Line	Light Rail	20	1994	No
Los Angeles	Red Line	Heavy Rail	11	1993	No
	Blue Line	Light Rail	22	1990	
	Green Line	Light Rail	20	1995	
Washington, D.C.	Red Line	Heavy Rail	4	1990	Yes
	Green Line	Heavy Rail	22	1991	
	Blue Line	Heavy Rail	7	1991	

Data Source: Baum-Snow & Kahn (2005)

The different urban settings in these four regions offer several dimensions of variation that may illuminate the significance of project context on the densification effect of urban rail transit. Chicago and Washington, D.C. both had well-established rail transit network before 1990, while the other two just started their rail transit from scratch in the 1990s. Given the notion that expanded rail systems may have higher utilities than brand new ones due to the network effect (Baum-Snow & Kahn, 2005), these cases consist a representative sampling of both types. In addition, these four cases happened to include both types of urban rail transit as defined in this study—heavy rail and light rail. Especially, since the Los Angeles case includes both types of systems, it provides a useful natural experiment to test whether and how one of these two types of urban rail systems affects the densification effects of rail transit differently than the other.

3.4 Methodology

To study the densification effects in the four case regions and answer the research questions, this research applies a mixed methodology of spatial analysis, regression analysis, and case analysis. This section will explain how each type of analysis is carried out in this study.

1) Spatial analysis

Since the primary goal of this research is to explore the different trends in densification between neighborhoods close to new rail stations and neighborhoods at other locations, it will deal with lots of spatial data. Therefore, spatial analytical tools will be used intensively. Spatial analysis is a general term to describe a method which uses location information of datasets to analyze attributes associated with locations. Since the late 20th century, spatial analysis has become a fundamental part of scientific inquiry in the field of geography, environmental sciences, and urban planning (Fotheringham & Rogerson, 2009).

There are many tools available for conducting spatial analysis. To explore the spatial patterns of density change in the four case regions, this research uses the spatial analytical tools built in the ArcGIS software package. ArcGIS is a popular tool commonly used for spatial data storage and visualization (Rosenberg & Anderson, 2011). In particular, this research will rely on the Hot Spot Analysis tool in the Spatial Statistics toolbox offered in ArcGIS to figure out where the highest and lowest density change clustered within each case region. Hot spot analysis, by definition, is "the process of finding unusually dense event clusters across space" (Fotheringham & Rogerson, 2009), thus it is the suitable tool for the purpose of this research. In particular, the Hot-Spot Analysis tool offered by the ArcGIS software can calculate the Z-score of each neighborhood in terms of density change among all neighborhoods in the region. A neighborhood with a high Z-score, for example, larger than 2, is a statistically significant hot spot in terms of increase in density. Compared to the standard statistical tools that simply calculate the sample variance and Z-scores, hot spot analysis also takes into consideration the spatial relationship between neighborhoods. To be a statistically significant hot spot, a neighborhood will have a high value and be surrounded by other features with high values as well. In other words, this eliminates the random outliers but reveals the real pattern spatial clustering.

Using thematic maps to visualize the results of hot spot analysis, this research is able to present where statistically significant densification happens across space and whether the locations of high densification are overlapped with the locations of the new rail transit stations. Chapter 4 will show the findings of spatial analysis for the four case regions.

2) Regression analysis

Spatial analysis can generate visualization of densification and inform us whether there are possible densification effects near new rail stations. To estimate the size of the densification effects, this research will use regression analysis. Regression analysis is widely used in social sciences to evaluate the association between multiple factors. However, to take one step further from establishing association to revealing causality, special econometric techniques are needed in conducting regression analysis. These techniques include: randomized control trials, propensity score matching, regression discontinuity design, difference-in-differences design, and constructing instrumental variables (Khandker, Koolwal, & Samad, 2010).

This research will use the difference-in-differences (DID) design to estimate the densification effects of the new rail transit projects in the four case regions. DID design is of particular use when we need to evaluate the impacts of a certain policy intervention that is not a randomized controlled experiment. Policy interventions such as the development of a new rail station can be seen as "quasi-experiments". In the case of new rail transit investments, the opening of a new rail station/line is like a "treatment" of an experiment. The impacts of the new station/lines are the treatment effects that can be evaluated through regression models using DID design. In this design, this study quantifies the densification effects of a new rail station by comparing the different densification trends over time between the neighborhoods that are affected by the new rail station/line and those that are not affected.

According to the theories and literature, the impacts of a new rail station/line have an effective impact range. Therefore, neighborhoods that are out of this range would not receive this "treatment" and become the "control" group, namely, the counterfactuals. Using the control group as the baseline, DID analysis accounts for changes over time unrelated to the intervention and isolates the impacts of such intervention from the underlying time trends (Athey & Imbens, 2006). Ideally, by picking a control group that is similar to the treatment group in every way except for the treatment, DID econometric models can estimate the treatment effect in an unbiased way through comparing the difference of the change before and after the treatment between the treatment group and the control group (Card & Krueger, 1994). Therefore, the DID method is especially useful in evaluating policy shocks in complicated environments where general trends may be present, such as in the process of urban growth. This makes DID a suitable tool for the quantification of the densification effects of urban rail transit in this study. The next three subsections will describe the details of constructing regression models using the DID design in this study.

(1) Unit of analysis

To estimate the densification impacts of the new transit services in surrounding neighborhoods, the unit of analysis of this research, ideally, would be "neighborhoods". For the convenience of data collection and analysis, census block groups, boundaries as defined in Census 1990, were used as an approximation to "neighborhoods" in this paper. As this research involved data in two periods—pre-project (Year 1990) and post-project (Year 2010[2]), it is imperative that the geographic unit keeps consistent from time to time. Unfortunately, the demographic data collected for post-project period—ACS 2006-2010 data—currently use Census 2010 geographic area boundaries (U.S. Census Bureau, 2010), which are different from the Census 1990 boundaries. Therefore, a spatial interpolation method is used to split the Census 2010 blockgroups into small pieces that could entirely be enclosed by a Census 1990 blockgroup. The features of the Census 2010 blockgroups are then summarized by aggregating those pieces based on the Census 1990 boundary. The assumption of doing so without data distortions is that all neighborhood features are distributed evenly throughout each blockgroup. Although it does not holds true in reality, the errors should not be significantly large enough to bias the analytical results.

[2] From American Community Survey data, it will be 5-year average values from 2006 to 2010.

(2) Identification of treatment and control groups

According to the DID concept, this study selects two groups of neighborhoods in each case region: the treatment group and the control group. The treatment group contains the neighborhoods that are (supposed to be) affected by the new transit lines. The control group contains the neighborhoods that are similar to the neighborhoods in the treatment group in nearly every other aspect except that they are within the impact range of the new transit stations. The underlying assumption is that the densification trend in the control group can be considered as a proxy for the hypothetical densification trend that "would have occurred" in the treatment group, should the new transit services never happen. Simply put, those neighborhoods in the control group serve as the counterfactuals of the treatment neighborhoods.

Because the line and the stations of a new rail project have difference impact rages, this study uses two different ways to define the "treatment" caused by urban rail transit investments and constructs two sets of models accordingly—the corridor models and the node models. In the corridor models, neighborhoods located within a half mile along the track of the target rail Line form the treatment group. The control group in the corridor models, by contrast, consists of neighborhoods located within a half mile from selected bus lines. These bus lines served as the counterfactuals of the target rail Line. Both bus transit and rail transit are major public transportation modes which carry a large number of passengers. The rationale of using bus lines as the counterfactuals of the rail lines is that a new urban rail transit line is most likely to be planned along a route which captures a high demand for public transportation. In most cases, such a route represents a heavily-loaded bus corridor that already exists in the public transit system. To ensure the comparability between the rail line and the counterfactuals, the selection process of the counterfactual bus lines applies three criteria. First, the bus lines should run in the same direction as the rail line does, e.g. from city center to suburbs, or from north to south. Second, the bus lines shall be outside of a half-mile buffer zone of all the rail transit lines in the area, to prevent any interference caused by transit lines. Lastly, among all those bus lines which meet the first two criteria, bus lines with higher ridership shall be selected. When the bus lines include redundant circuits, minor editing is made on the bus routes to simplify the routes while still maintaining their shape and direction for the analysis purpose.

In the station models, only the neighborhoods located within a half mile from the stations on the target rail Line make the treatment group. The control group only contains neighborhoods within a half mile from selected bus stops on those selected counterfactual bus lines in the corridor models described above. The selection of these counterfactual bus stops follows two steps. First, the major stops on the time table of each counterfactual bus line become the first candidates. The rationale behind this decision is that these stops on the time table should be the major nodes of transport importance along the route, thus sharing similar location significance as the stations on the target rail Line. Second, a four-to-six-minute spacing rule is applied to ensure that these counterfactual bus stops would have similar spacing as the rail line stations. Therefore, a major bus stop would be removed if the travel time from its neighboring stops is shorter than four minutes. A new intermediate bus stop would be added if the travel time between two neighboring major stops on the same bus line is longer than eight minutes. In both the corridor models and node models, the neighborhoods located within a half mile from any pre-existing rail line are excluded from the sample, in order to prevent any estimation bias caused by the impact of those rail lines.

(3) Model construction and finalization

The regression models for both the corridor models and the node models share the same structure. The models include a dummy variable of treatment assignment to estimate the treatment effects of new rail station/line on the neighborhood density change indicators—indicators reflecting the density change in population or housing units. Variables of pre-treatment neighborhood conditions are controlled for in these models. The interaction terms of neighborhood conditions and the dummy variable of treatment assignment are also included in the models to estimate how the densification effects can be influenced by exogenous neighborhood factors. In mathematic terms, the regression models are written as:

$$
\begin{aligned}
\Delta Y_i \quad &= Y_i^t - Y_i^{t-1} \\
&= \alpha + \underline{\boldsymbol{\beta}}\boldsymbol{X_i} + \gamma T_i + \underline{\boldsymbol{\mu}}\boldsymbol{X_i} \cdot T_i + \varepsilon_i \qquad \text{(Equation 1)}
\end{aligned}
$$

Where: ΔY_i is the change (from 1990 to 2010) in a selected neighborhood indicator Y (density of population or housing units) for neighborhood i ; Y_i^{t-1} is the measurement of indicator Y for neighborhood i at the pre-treatment time (in 1990); Y_i^t is the measurement of indicator Y for neighborhood i at the post-treatment time (in 2010); α, β, γ, and μ are parameters to be estimated in the regressions; ε_i is the error term; $\boldsymbol{X_i}$ is a vector of exogenous or pre-treatment characteristics of neighborhood i, such as the geographic, demographic or socio-economic features in 1990; T_i is a dummy variable of treatment group assignment for neighborhood i, which equals 1 for being in the treatment group and 0 for being in the control group; $\boldsymbol{X_i} \cdot T_i$ is a matrix of all the interaction terms between the treatment variable and the neighborhood-specific variables, whose coefficients estimate how the neighborhood features affect the magnitude of the densification effect of the treatment. For each case region, four regression models are constructed: corridor model on population densification, corridor model on housing densification, node model on population densification, and node model on housing densification.

To carry out the regression models listed above, this study uses the SPSS software and enters into the regression models all the independent variables that fall in four categories: treatment dummies, station features, neighborhood factors (including geographic features and socio-economic features), and the interaction terms between treatment dummies and neighborhood factor variables. The criteria of selecting a final model include the following steps. Firstly, a review of previous studies as described in Chapter 2 provides a starting set of possible independent variables that need to be included. Secondly, the “stepwise” method is used to filter those variables and keep only the ones that are at least statistically significant at the 0.10 level in each model. Finally, to make the coefficients comparable between the corridor and node models as well as population and housing densification models, this study synthesizes all four models for each case region and constructs a composite model structure that contains all the independent variables that are statistically significant in at least one of the four sub-models.

3.5 Data sources

To fulfill the three types of analysis, this research collects five categories of data from various sources. These data and their sources are listed below.

(1) Transit lines and stations information

This research will obtain the spatial data files containing the locations of the new (and any pre-existing) transit stations and lines from individual transit authorities of the four metropolitan regions. The accuracy of the spatial information is the key to the validity of the difference-in-difference analysis in this research, which will be elaborated later in this section. Therefore, this research checks the data validity using the geographic information of transit stations from Google maps and compares it to the spatial data provided by the transit authorities for randomly sampled transit stations. If there are considerable discrepancies between the two, a third source (such as newspaper reports or planning meeting minutes) on the station location information will be used. In addition to their geographic locations, this research also obtains other station-specific features such as number of parking spots, fare to other stations from the transit authorities.

2) Neighborhood conditions: density, demographic and socio-economic information

Indicators used to describe the density changes and the exogenous factors of the neighborhoods are retrieved from census 1990 sample data SF3 and American Community Survey (ACS) 5-year average from 2006-2010. These measures are used to identify the pre- and post-treatment conditions of the neighborhoods. Unlike decennial census which collects data of a point date, American Community Survey 5-year estimates are period estimates, meaning that they represent the characteristics of the population and housing over a specific data collection period. For example, the data of 2006-2010 ACS 5-year estimates were collected between January 1, 2006 and December 31, 2010 (U.S. Census Bureau, 2011). Therefore, it is not a perfect idea to compare 5-year average values from ACS to the point estimate from Census 1990. However, ACS is the only available dataset containing socio-economic variables since Census long form discontinued after 2000. ACS provides a comprehensive set of up-to-date demographic and socio-economic indicators. Moreover, 2006-2010 ACS 5-year estimates use the same geographic boundaries of block groups as that of Census 2010, thus it can be cross-validated with census 2010 data. The strength of the ACS is in estimating characteristic distribution within certain geographic areas.

(3) Job counts and accessibility to jobs

As one of the aspects regarding the features of rail transit stations, the accessibility to jobs by transit is an important piece of information. Ideally, the accessibility score should measure the weighted total number of jobs that could be reached along the rail lines/stations. However, due to the limitation of data availability, this research uses a proxy accessibility measure that accounts for the weighted total number of jobs reached by transit in the entire metropolitan area. In addition, since this study focuses on residential densification rather than commercial or employment densification, the accessibility measure used in this research is an indicator of trip generation rather than trip attraction. In other words, it measures the ease of access from the rail station of interest to the destinations in the rest of the metropolitan areas, without considering the attractiveness of the station area in terms of accessibility. The data on accessibility scores are obtained from two previous studies on intermetropolitan accessibility comparisons (Grengs, et al., 2010; Levine, et al., 2012). The employment data used to calculate the accessibility scores come from the business database operated by a private vendor Claritas. The same employment dataset is used in this research to analyze the spatial pattern of job distribution and to determine the geographic boundary of the “downtown” in Denver and in Los Angeles.

(4) Public records and media reports

To learn the background of the rail transit projects in the case cities, this research searched for and collected data from public records and media reports, including newspapers, planning meeting minutes, historical maps, photos, property transaction records, and other publications that commented on the new transit services. Most of them are dated back to the time when the new transit was planned, designed, and placed in service. This group of data is retrieved from internet search engines and online databases, the ProQuest Historical

Newspapers and the World Newspaper Archive. Several key words are used in conducting the search, including: “density”, “population”, “gentrification”, “employment”, “job”, “Transit-Oriented Development or TOD”, “commute”, “business”, “investment”, “growth”, “income”, “low-income”, “resident”, “NIMBYism”, “public hearing”, and “community”.

(5) Supplementary spatial data for mapping

For the purposes of spatial analysis and data visualization, this study also needs some supporting spatial data, including the boundaries of census block groups and other jurisdiction boundaries, the layer of the rivers and lakes, major streets and highways, landmarks, to name a few. These data are mostly downloadable from the Census website, in the format of TIGER 1990 and 2000 shapefiles. Whenever a data file is not available from the Census website, transit agencies and/or planning departments of the case region are approached for the according data request.

Summary of research design and methodology

A conceptual framework derived from the literature review of Chapter 2 explains the mechanisms of the potential densification effects of urban rail transit from the perspective of residents and developers. For each individual, if the rail transit brings more benefits than costs, he/she will be attracted to live in the station-area neighborhoods. If more people choose to live in rather than move out, the neighborhoods will experience population densification. As one step further from population densification, housing densification needs another condition—the permission to build dense housing development in the area. In order to allow for the dense development to happen, restrictive land use and zoning barriers need to be removed and a pro-density neighborhood attitude is also important.

Based on the conceptual framework, this research raises four specific research questions. The first question directly corresponds to the inquiry of whether densification effects were observed following new urban rail transit, and in determining the degree to which density changed. The rest questions explore the relationship between the densification effects of new rail transit and exogenous factors at multiple levels. The answers to these research questions will help to inform neighborhood residents, policy makers and transit planners to improve related policy interventions in the future.

To answer these research questions, this study applies spatial analysis, regression analysis and case analysis. In spatial analysis, this research uses thematic mapping to present the patterns of densification and uses hot spot analysis to visualize where high levels of densification clusters across space in ArcGIS. In regression analysis, this research applies the regression models with a difference-in-difference design to quantify the densification effects of a new rail station. The inclusion of the interaction terms between neighborhood condition indicators and the dummy treatment variable gives the models explanatory power to answer the research questions on how the densification effects could be affected by exogenous factors. In case analysis, this research selects one station area that experienced noteworthy densification effects and thoroughly studies the history of the neighborhood change and the public responses to such a change. The three methods of analysis complement each other and help to describe the full story behind the densification effects of rail transit investments.

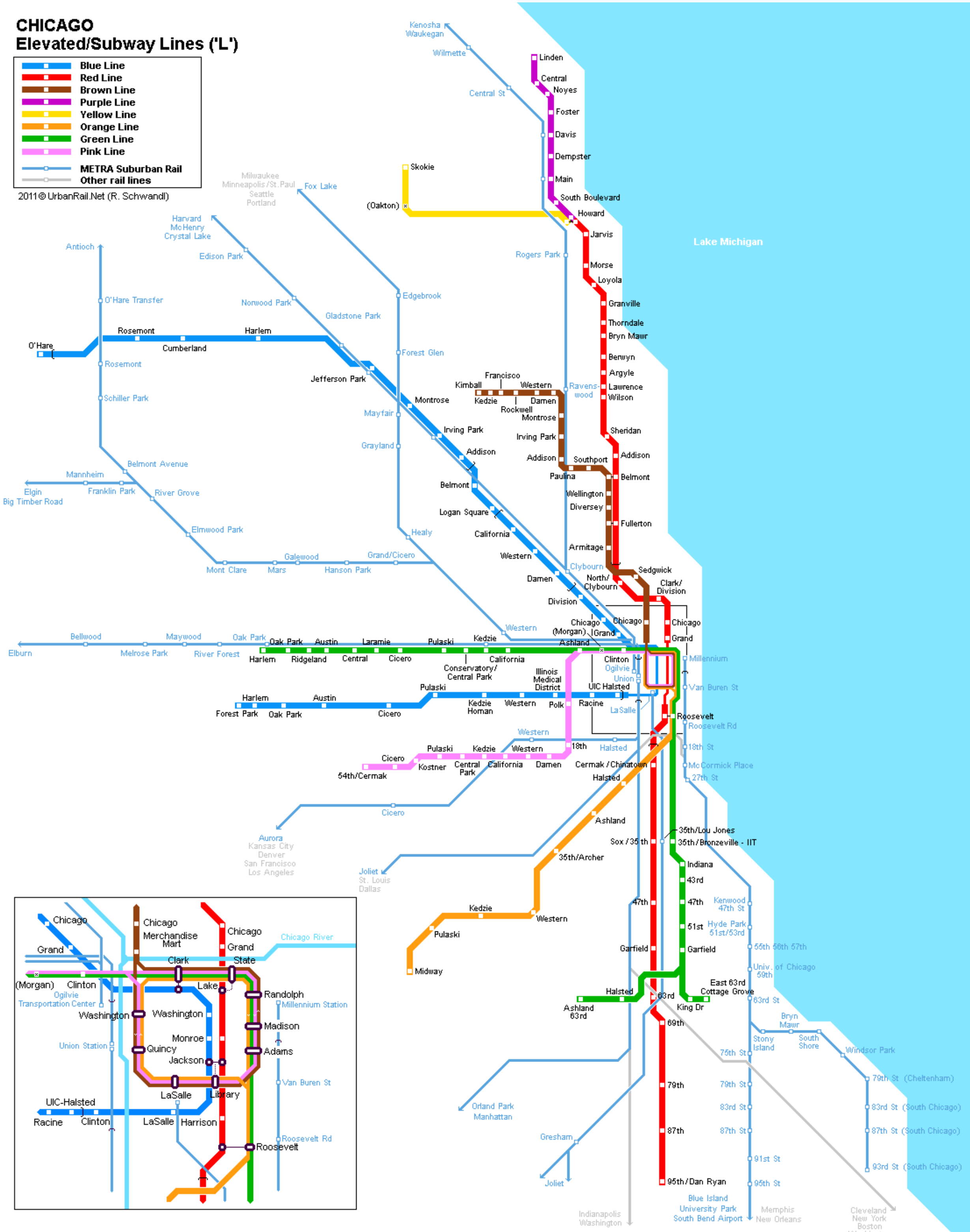
Chapter 4: Case descriptions: the recent rail transit developments in the four case regions

This chapter presents the history and background of the rail transit investments in each of the four case regions. It contains four sections, each of which discusses one case region. From hereafter, this study will use the phrase “the lines under study” to denote the urban rail transit lines in the four case regions that this study select in this research, which include: the Orange Line in Chicago, the Green Line in Washington, D.C., the D Line in Denver, and the Blue, Green, and Red/Purple lines in Los Angeles.

4.1 The Orange Line in the Chicago region

Chicago’s current regional transit agency, the Chicago Transit Authority (CTA), operates heavy rail and bus facilities in Chicago and 38 suburban municipalities. The size and the ridership of rail and bus transit are comparable to each other. There are seven primary rail lines (Map 2) totaling about 225 route miles and 143 rail stations, with 560,000 passengers on an average weekday. There are 134 bus routes with 960,000 passengers on an average weekday.

The history of the CTA-operated rail transit system in Chicago—dates back to 1924. Before 1990, Chicago already had a well-established rail transit network, yet most of the stations were located in the north part of the city, leaving Southwest Chicago under-served by rapid transit. During the 1990s, two new lines were constructed: the Orange Line and the Green Line, connecting Southwest Chicago and South Chicago to downtown area, respectively. Although the opening dates of the Orange Line and the Green Line both meet the time frame required in this research—in the 1990s, this study will only focus on the case of the Orange Line for analyzing the densification effects.



Map 2: The urban rail transit system in Chicago (Schwardl, 2013)

The Green Line is dropped from the analysis for two reasons. The major reason is that the Green Line is two close to the other two older rail lines—most of the Green Line stations are located within a half mile from a station on the Red Line or the Blue Line. This makes it very difficult to separate the densification effects of the Green Line from any possible impact from the other two older lines. Another reason to drop the Green Line from the analysis is the discontinuity in the service. Opened in 1993, the Green Line was consolidated and realigned based on two oldest rapid transit lines in the city, which were too deteriorated to continue service (Chicago "L".org, 2011). Soon after its creation, the service on the Green Line was suspended from 1994 to 1996 for a rehabilitation project, and the line continued to run after 1996 until today. This two-year gap is very likely to have negatively affected the accessibility (and the attractiveness in general) of the area around the Green Line stations, therefore, including the Green Line in the analysis may underestimate the densification effects of the urban rail lines of the 1990s in Chicago.

The Orange Line, sometimes referred to as the Midway Rapid Transit Line or the Southwest Side Rapid Transit Line (McMillen & McDonald, 2004), was opened on October 31, 1993. With a total distance of eleven miles in track length, the Orange Line connects downtown Chicago to the Midway Airport. The track begins at Midway Airport at 59^{th}/Kilpatrick and connects to the “Loop”, with seven stations approximately one mile apart, plus a station at Roosevelt/Wabash to serve Orange and Green Line trains. The Orange Line provides the first rapid transit service to the southwestern neighborhoods of the city, where transit service fell far behind all other sectors until the late 20^{th} century.

The idea behind the planning of the Orange Line could dated back to 1958, when the Chicago Transit Authority released its report on transportation planning for the greater Chicago region—“New Horizon for Chicago’s Metropolitan Area”. The report called for new transit corridors, including subways under Wells Street and Jackson Boulevard, a bus lane in the median of Stevenson Expressway, and several rapid-transit lines down the medians of several other superhighways (Schwieterman & Mammoser, 2009). The bus lane in the median of Stevenson Expressway, which was never built, ended up being the route over which the Orange

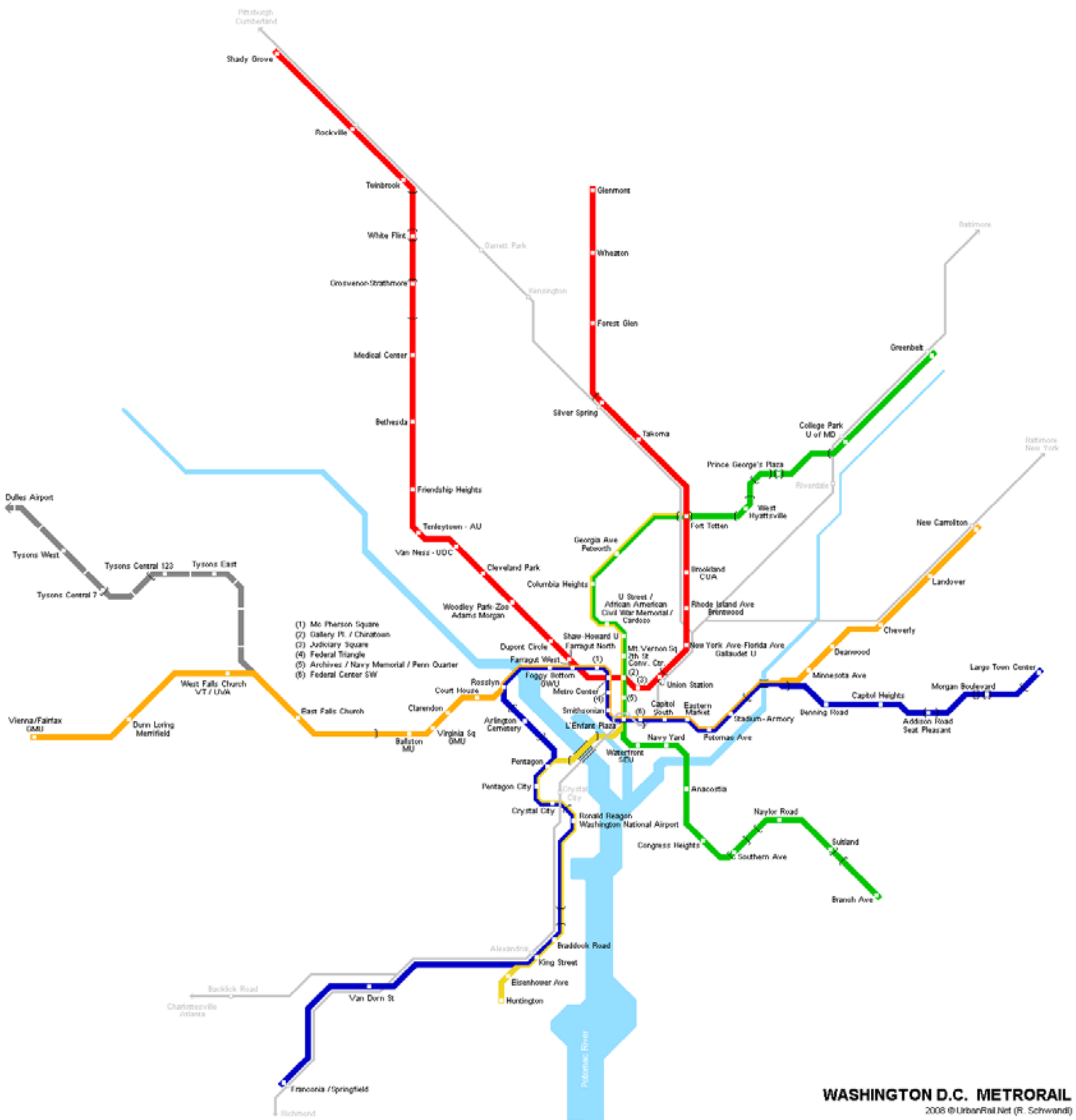
Line was finally constructed more than thirty years later. Perhaps the most critical period along the planning process of the Orange Line was 1979-1983, when the Mayor of Chicago Jane Byrne and the Governor of Illinois James Thompson decided to transfer the funds reserved for the planned (and then cancelled) Cross-town Expressway to CTA, who used the money to finance the Orange Line project (Schwieterman & Mammoser, 2009). The total capital investment on the Orange Line (including property acquisition, track and station construction, as well as rolling stock purchase) costs around $510 million, 85% of which came from the Federal Transit Administration and the remaining 15% from the State of Illinois (McMillen & McDonald, 2004). The city agreed to cover any cost overruns with the proceeds of bond issues (Washburn, 1986). After the funding agreement was reached by the city, state and federal governments, the construction of the Orange Line soon began in 1987, which was then completed in 1993.

The long-time expected Orange Line was widely accepted among politicians and civic leaders from the very beginning. Studies (McDonald & Osuji, 1995; McMillen & McDonald, 2004) found that the land values within one-half mile of the station sites increased by 17% three years before the line opened in 1993. On the day when the project proposal was finally approved, Governor James Thompson appeared at a press conference and announced that the project "will redeem the faith of the people of the Southwest Side of Chicago, who have been waiting for a long time" (Washburn, 1986). The media also reported extensively positive reactions among the business owners and local residents. For example, the spokesman for the Midway Airport Tenants Association referred to the Line as "the shot in the arm that the southwest corridor needs for continued resurgence"(Washburn, 1986). The president of the West Elsdon Civic League, a neighborhood group of the West Elsdon community where the Orange Line serves, told the newspaper reporter that they "have been fighting for this for a very, very long time…. We never thought the federal government would ante up" (Washburn, 1986). According to the information released at a press conference, southwest side Congressman William Lipinski (Democratic) played a key role in achieving the federal support for the Orange Line, as he personally called for President Reagan's attention on the project after providing critical support for the Republican President's proposal of aid to Nicaraguan Contra rebels (Washburn, 1986). The Congressman reportedly (McDonald & Osuji, 1995) replied to the President when he was called by the President and asked if there were anything he needed: “Mr. President, have you ever heard of the Southwest Side Rapid Transit Line?” Lipinski also had high expectations for the benefits of the Orange Line, which he predicted to generate “unprecedented economic development on the Southwest Side” (Washburn, 1986).

The Orange Line is an entirely new transit line that replaced a bus service and attracted commuters who used to drive. After its operation, ridership on the Orange Line was better than expected (Chicago "L".org, 2011), which confirmed the demand of rail transit service in previously under-served Southwest Chicago. Ridership on the line was initially projected to be 25,000 riders per weekday, while the actual ridership in the first year was 28,000 per weekday. As of January 2013, the fare is $2.25 for a one-way trip from any station on the Orange Line to Downtown Chicago. The travel time from Midway Airport to Downtown Chicago on the Orange Line is 30 minutes, while express bus for the same trip during peak hours would need over 45 minutes. The history behind the Orange Line shows that it was a well-expected and well-received public investment at the time. This research will conduct analysis to see whether this line has generated densification effects on the surrounding neighborhoods.

4.2 The Green Line in Washington, D.C. region

Compared to some other major cities in the United States, Washington, D.C. has a fairly short history of rail transit. Born in 1976, the rail system of the Washington, D.C. metropolitan area, also called Metrorail, or Metro, continued to expand ambitiously in the 1980s, 1990s, and into the 21st century (Schrag, 2006). The entire Metro rail system (Map 3) now has five operating lines and covers the greater metropolitan area of Washington, D.C., including part of Maryland and Virginia, with a total of 86 stations and 106.3 miles of track (Washington Metropolitan Area Transit Authority, 2011). The popularity of the Metro in Washington, D.C. continues to grow after its opening. The system is now the nation’s second largest urban rail transit system in terms of track length and usage, only after New York City (Washington Metropolitan Area Transit Authority, 2011). The operator of the Metro rail, the Washington Metropolitan Area Transit Authority (WMATA), which also runs the bus system in the region, became the fourth largest transit agency in the United States (Federal Transit Administration, 2009).



Map 3: The Metro Rail system in Washington, D.C. (Schwardl, 2013)

The popularity of the urban rail transit in Washington, D.C. may be attributed to two reasons. One reason is the severe road congestion in the region. According to the measures in the Urban Mobility Report (Texas Transportation Institute, 2010), Washington, D.C. is ranked as the fourth most congested regions in the United States, only after Los Angeles, New York and Chicago. Moreover, although new roads were built and expanded, the vehicle miles traveled in the Washington metropolitan area kept rising and exceeded the road capacity (P. Nelson, et al., 2007). The other reason is the continuing densification of the urban core. As the capital of the nation, the federal government is the driving engine of the local economy, attracting many residents and activities to the center of the region (P. Nelson, et al., 2007). Therefore, unlike some other American cities with a declining downtown, Washington D.C. remains fairly dense in the central city. As cited in Huang (1996), one of the objectives of the Metro rail system is "to support a compact pattern of regional centers along major corridors radiating out from a strong downtown". Moreover, the local transit agency adopted "Joint Development Policies and Guidelines" to promote high-density development near rail stations, so did they advocate for dense development in front of the public, the local governments, and the developers[3]. Previous studies also showed that such policies did post positive some impacts on development around the rail stations, such as increased rent and decreased vacancies for office buildings, larger shares of regional development and higher rates of employment (Cervero, 1994a; Green & James, 1993).

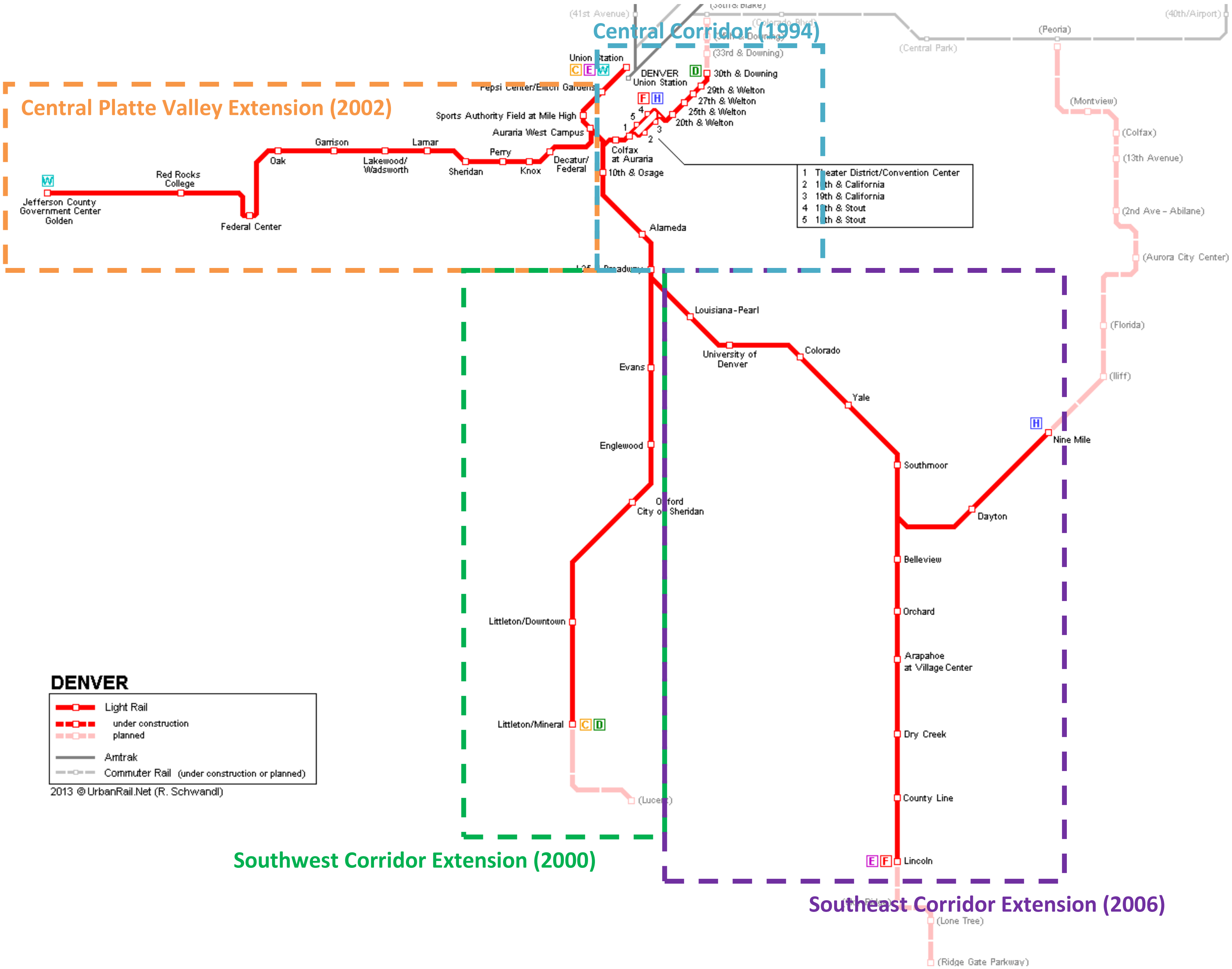
However, the transit options are fairly limited outside of the central city until the 1990s and the 2000s, when the Red Line and the Blue Line were both extended to the suburbs and a new line, the Green Line, was built. The Green Line is a heavy rail line of stations, running through D.C. and Prince George's County, Maryland, with Branch Ave. Station as its south terminus and Greenbelt Station as its north terminus, as shown in green color in the system map (Figure 20). All the stations (except for the ones shared with other lines) on the Green Line were constructed and opened between 1991 and 2001. As the newest line of the system, the Green Line and its neighborhood impact had not been systematically studied and documented. Therefore, it becomes a good candidate for the purpose of this study, which looks into the population and housing density change in the surrounding neighborhoods of the Green Line from 1990 until 2010 and provides the latest evidence on the densification effect of the Metro in the new century.

[3] According to Section 11.0 of the WMATA Joint Development Policies and Guidelines (Washington Metropolitan Area Transit Authority, 2008), it states that "WMATA staff will participate cooperatively in local planning processes to advocate for conditions that will facilitate joint development projects that will create TOD, value for WMATA, and will create improvements in WMATA's transit facilities".

4.3 The D Line in the Denver region

As one of the newest rail transit systems in the country, the Light Rail Transit (LRT) system in Denver now includes five fixed rail lines, 36 stations, 35 miles of tracks, and a total of 172 vehicles. Its operator, the Regional Transportation District (RTD), serves eight counties: the City and County of Denver, the City and County of Broomfield, the counties of Boulder and Jefferson, the western portions of Adams and Arapahoe Counties, the northern portion of Douglas County, and small portions of Weld County. As of Year 2012, the average number of weekday boardings on the Denver LRT is 328,109 (Denver Regional Transportation District, 2013b), and the total unlinked passenger trips was 20,087,700, ranked the eighth in the country (American Public Transportation Association, 2012).

The Denver metropolitan area first implemented light rail transit (LRT) in 1994 with the Central Corridor Line, followed by the Southwest Corridor extension in 2000, the Central Platte Valley extension in 2002, and the Southeast Corridor extension in 2006. These four corridors made up the five lines currently running in the region (Map 4).



Map 4: The light rail transit system in Denver, Colorado

The C Line, consisting of the Central Platte Valley extension, part of the Central Corridor and the Southwest Corridor, runs from the Union Station in Downtown Denver to the Littleton/Mineral Station in the south. The D Line, consisting of the Central Corridor and the Southwest Corridor, runs from the 30th/Downing in Downtown Denver to the Littleton/Mineral Station in the south. The E Line, consisting of the Central Platte Valley extension, part of the Central Corridor and the Southeast Corridor, runs from the Union Station to the Lincoln Station in the south. The F Line, consisting of the Central Corridor and the Southeast Corridor, runs from the 18th/California in the north to the Lincoln Station in the south. The H Line, shares mostly the same track of the F Line, except that it reaches the Nine Mile Station in the South instead. A sixth line, also the newest one, the W Line will be opened in April 2013.

Given the period focus of this research, this study only chooses the D Line as the study case for evaluating the densification effects of light rail in Denver. The D Line is the combination of the Central Corridor and the Southwest Corridor, both of which are entirely built between 1990 and 2000. The Central Corridor segment of the D Line runs from 30th Avenue & Downing through the Five Points Business District and downtown Denver to I-25 & Broadway, with 14 stations and a total length of 5.3 miles (Denver Regional Transportation District, 2013a). The Southwest Corridor segment connects to the Central Corridor at the I-25 & Broadway Station and extends to the downtown of the City of Littleton, with five stations and a total length of 8.7 miles (Denver Regional Transportation District, 2013c). The track of this segment was built entirely on the reserved right-of-way of an existing railroad. As for the funding sources, the $116.5 million gross capital cost of the Central Corridor segment was funded entirely by RTD with an existing use tax, RTD's capital reserve and bonds issued by RTD. By contrast, the $177.7 million project cost of the Southwest Corridor extension was majorly funded by federal sources, including the $120 million Full Funding Grant Agreement signed by the U.S. Secretary of Transportation in 1996 and the $18 million flexible highway-to-transit funding provided by the Federal Highway Administration (Denver Regional Transportation District, 2013c).

Stimulating development around the rail transit stations was one of the goals of RTD. RTD even hired a Transit-Oriented Development specialist in June 2000, whose responsibilities include "working with other agencies, local jurisdictions and developers to encourage TOD" along the light rail stations of RTD (California Department of Transportation, 2002). However, the efforts to build densely around the station areas were sometimes dismissed by local residents. In the past, at least a couple of proposals brought to RTD by developers were turned down because of neighborhood objection. For example, the college has proposed student housing near the Aurora station but the neighbors strongly rejected it (California Department of Transportation, 2002). Given the tension between the two forces from the transit agency and the neighborhood, the actual outcome on the densification in the neighborhoods nearby the transit stations along the D Line would be questionable, which will be investigated in this study.

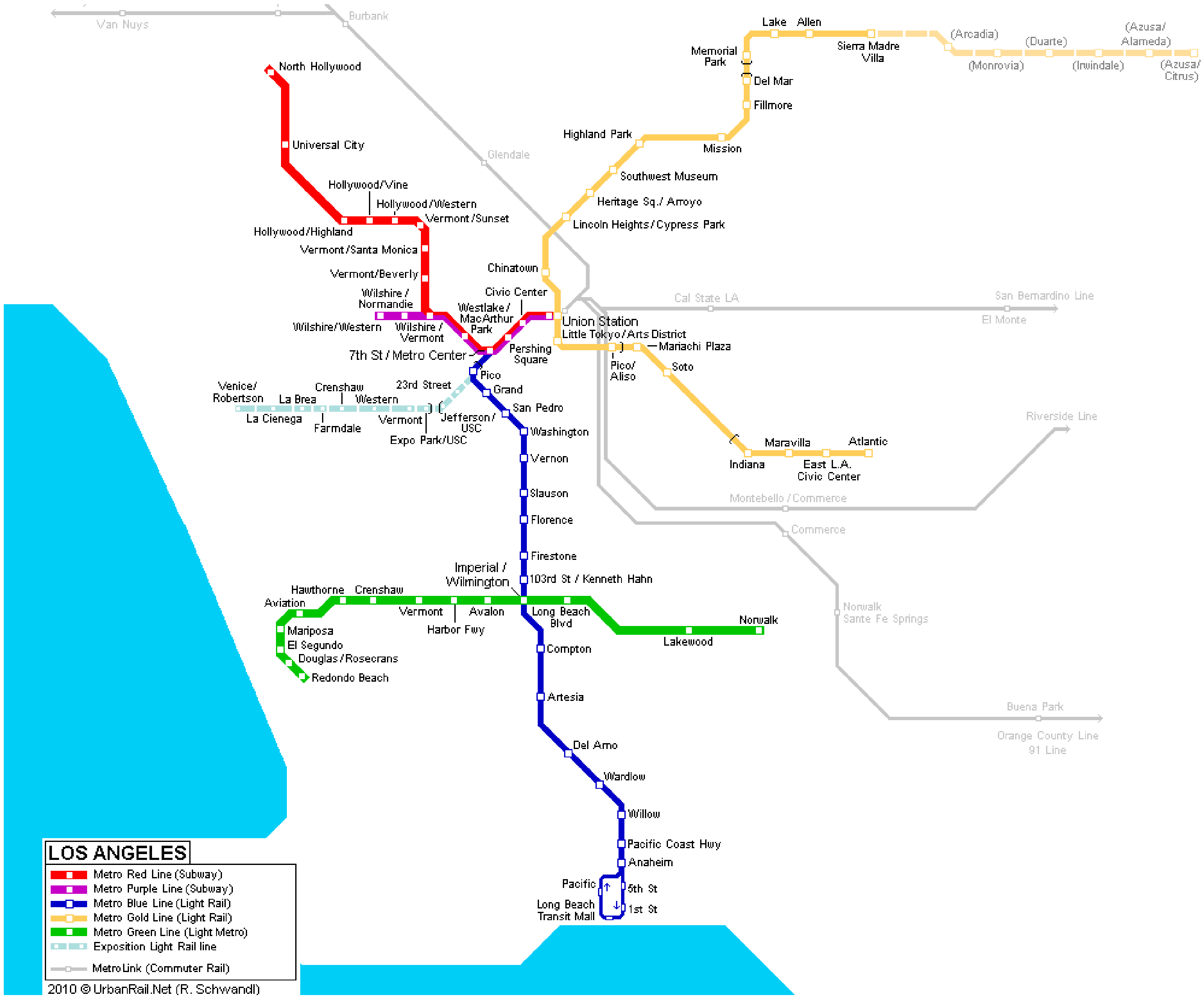
4.4 The Blue, Green and Red/Purple Lines in the Los Angeles region

As the second largest city of the U.S., Los Angeles is often viewed as one of the most heavily motorized and congested city, which is principally attributed to highway-oriented decentralization of employment throughout the region (Wachs, 1993). However, Los Angeles was actually once a leading city with the largest rail transit network in the U.S.—the Yellow Cars and the Red Cars running during the early 20th century. Due to the quick drop of ridership and the increasing popularity of motorized travel, all the streetcars in the Los Angeles area ceased operation by 1961. Since then, bus became the only public transportation mode (Richmond, 1998).

The rails were brought back to the region when Proposition A was approved in 1980 to build a rail rapid transit system in the Los Angeles County. In 1985, the Los Angeles County Transportation Commission (LACTC) selected light rail as the approach to build the new rail system in the area and chose to construct the first route—the 22-mile Blue Line between downtown Los Angeles and downtown Long Beach, which used the tracks of one of the Red Car old routes (Loukaitou-Sideris, 2010). The Blue Line was opened on July 14, 1990. Following that, two more rail lines were opened and put into service—the Green Line and the Purple Line—in the last decade of the 20th century. The Green Line runs east to west and began to operate in 1995. The Purple Line, later became part of the Red Line, is a subway line opened in 1993 and runs from downtown Los Angeles to the Westlake Station in the west. After that, the Red Line continued to extend, to Wilshire Station in 1996, to Hollywood Station in 1999, and finally to the North Hollywood terminus in 2000, which completed the full Red Line. In 2003, the fifth line, the Gold Line was opened, providing light rail transit service from downtown Los Angeles to the east part of the city. The most recent addition to the Metro Rail system is the Expo Line, which opened in April 28, 2012, running from downtown Los Angeles to Culver City to the west. It is expected to extend further to the west until Santa Monica, where stations are scheduled to open in 2015 (Los Angeles County Metropolitan Transportation Authority, 2010).

As the rail system expanded, the management of the public transportation system in the Los Angeles region was further consolidated by merging the LACTC with the Southern California Rapid Transit District into the Los Angeles County Metropolitan Transportation Authority (LACMTA) in 1993 (Los Angeles County Metropolitan Transportation Authority, 2010). Now LACMTA is the operator of all the six rail lines as well as the bus system in the region. Given the time frame that this study is focused on, this research opts to investigate the densification effects of the Blue, Green, and Red (including Purple) lines, only because all the stations on these lines were opened between 1990 and 2000. Map 5 on the next page shows all the lines in the current system of LACMTA Metro Rail.

Within the decade of 1990 to 2000, over $6 billion dollars were spent on the three rail lines built in the Los Angeles region. Despite the huge investment on the rail transit system, the majority users of public transportation in the Los Angeles region are bus riders. According to the most recent statistics of the LACMTA, the number of total bus boardings is three times of the total rail boardings (Jager, 2013). Unlike the Chicago Orange Line, which was majorly funded by federal funding, or the Denver D Line, which was mainly funded by the existing user tax and capital funds from the transit agency, the LACMTA made efforts to fund the rail system from its revenues. In 1993, it tried to raise the bus fare to fund its rail system, which stimulated strong public dissent among the bus users in the region and led to a lawsuit between the LACMTA and the Bus Riders Union in 1994 (Grengs, 2002). Given such a background, evaluating the densification effects of the urban rail transit system in Los Angeles has significant implications for the debate on resources distribution between bus and rail spending at the local transit agency. Moreover, since the region has a record of public awareness and influence on the transportation issues, it is especially important to explore the impact of neighborhood attitude towards development issues on the densification effect of rail transit in this case.



Map 5: The Metro Rail system of the Los Angeles region (Schwardl, 2013)

Summary of case descriptions

The four case regions have distinctive histories of urban rail transit investments. In the Chicago region, the history of the rail transit system dates back to 1924 but Southwest Chicago was not served by rapid transit until the 1990s when the Orange Line opened. The long anticipated Orange Line was widely accepted among politicians and civic leaders from the very beginning. Previous studies also showed evidence on the impacts of the Orange Line on increasing property values in proximity. This research will conduct analysis to see whether this line has generated densification effects on the surrounding neighborhoods. In the Washington, D.C. region, the Metro Rail system started in the 1970s, the time when the resurgence of urban rail investments began in the Untied Stated. A few studies systematically studied the development impacts of the Metro Rail and found that these stations did promote development nearby. However, as the newest line of the system, the Green Line, which was constructed and opened in the 1990s, has not been systematically studied and documented yet. Therefore, it becomes a good candidate for the purpose of this study.

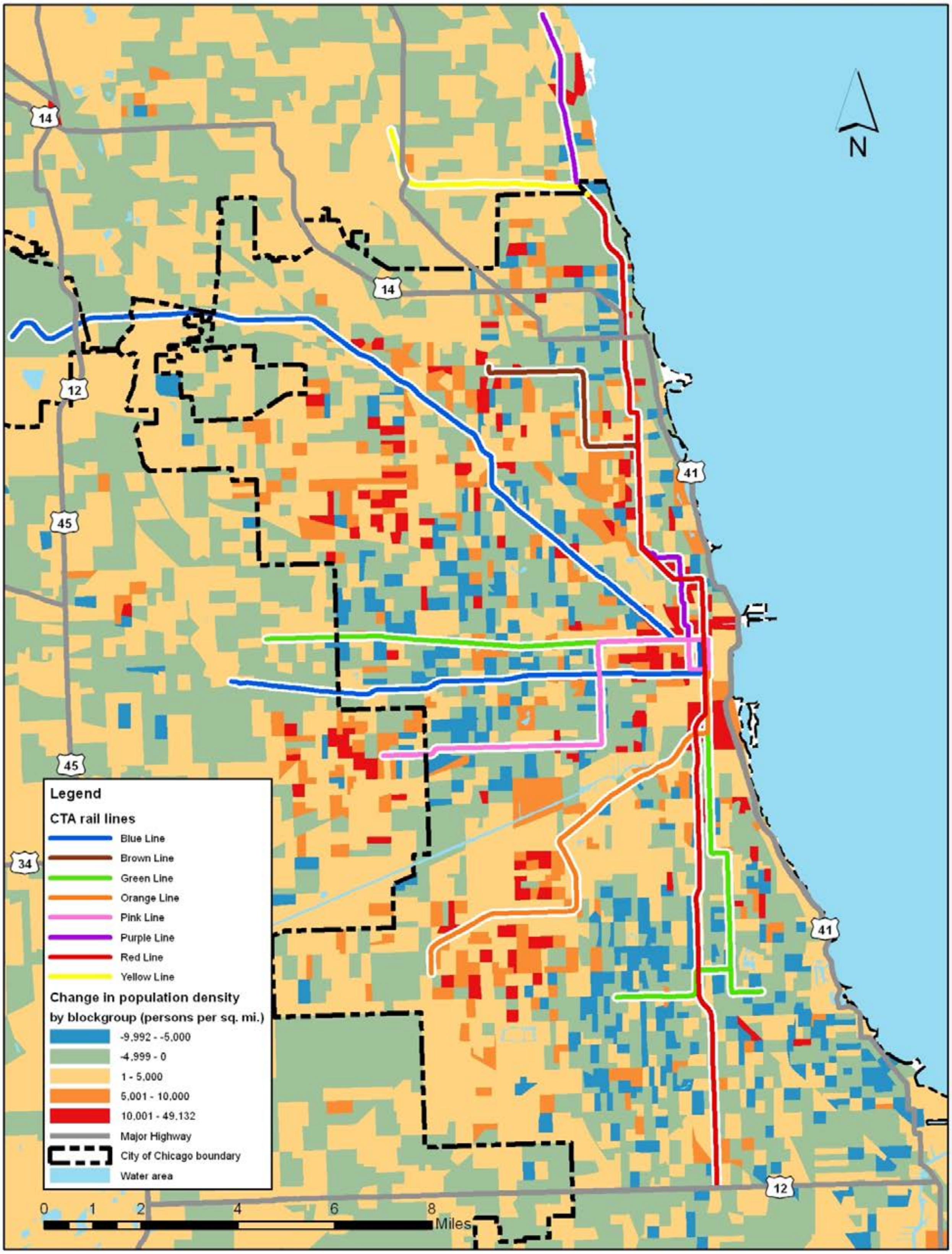
Unlike Chicago and Washington, D.C., Denver and Los Angeles did not have modern rail transit before 1990. In the Denver region, the first implemented light rail transit line did not open until 1994. Although the regional transit authority wants to stimulate development around the rail transit stations, Denver also has a history of neighborhood opposition to densification. Therefore, it would be essential to see the actual densification outcomes in the neighborhoods nearby the transit stations. In the Los Angeles region, the rail transit has been expanding very fast since its first opening in 1990. This research opts to investigate the densification effects of the Blue, Green, and Red (including Purple) lines, because all the stations on these lines were opened between 1990 and 2000. The fast expansion and big spending on rail investments raised some disputes and public resentment from bus riders in the Los Angeles region. Given such a background, evaluating the densification effects of the urban rail transit system in Los Angeles has significant implications for the debate on resources distribution between bus and rail spending at the local transit agency.

Chapter 5: Spatial analysis: exploring the pattern of density change in the four case regions

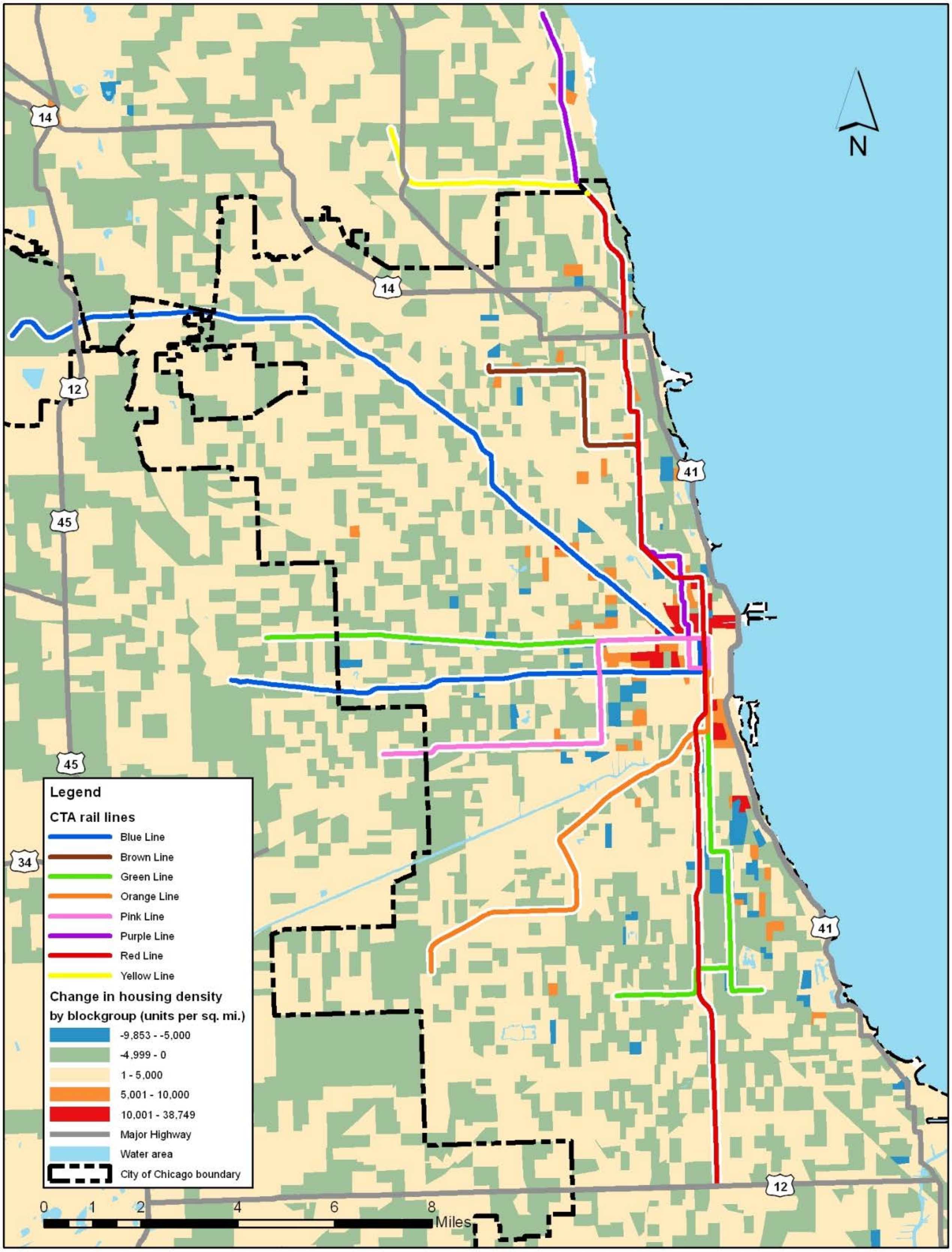
This chapter presents the results from spatial analysis. For each case region, thematic maps of the change in population density and housing density are made to visualize the general densification trend. These maps help us identify the spatial pattern of densification across the region. Based on the thematic maps of densification trends, this study continues with hot spot analysis to figure out if there are spatial clusters of densification that is statistically higher or lower than the rest of the region. The maps of hot spot analysis assist us in observing if there is higher densification near the newly constructed urban rail transit lines and stations than in other neighborhoods.

5.1 Chicago

Using data from Census 1990 and ACS 2006-2010, we calculate the density of each block group and the density change over the twenty years. The following are two thematic maps showing the density change in population and housing, respectively, from 1990-2010 in the Chicago region (Map 6 and Map 7).



Map 6: Change in population density by blockgroup in Chicago, 1990-2010

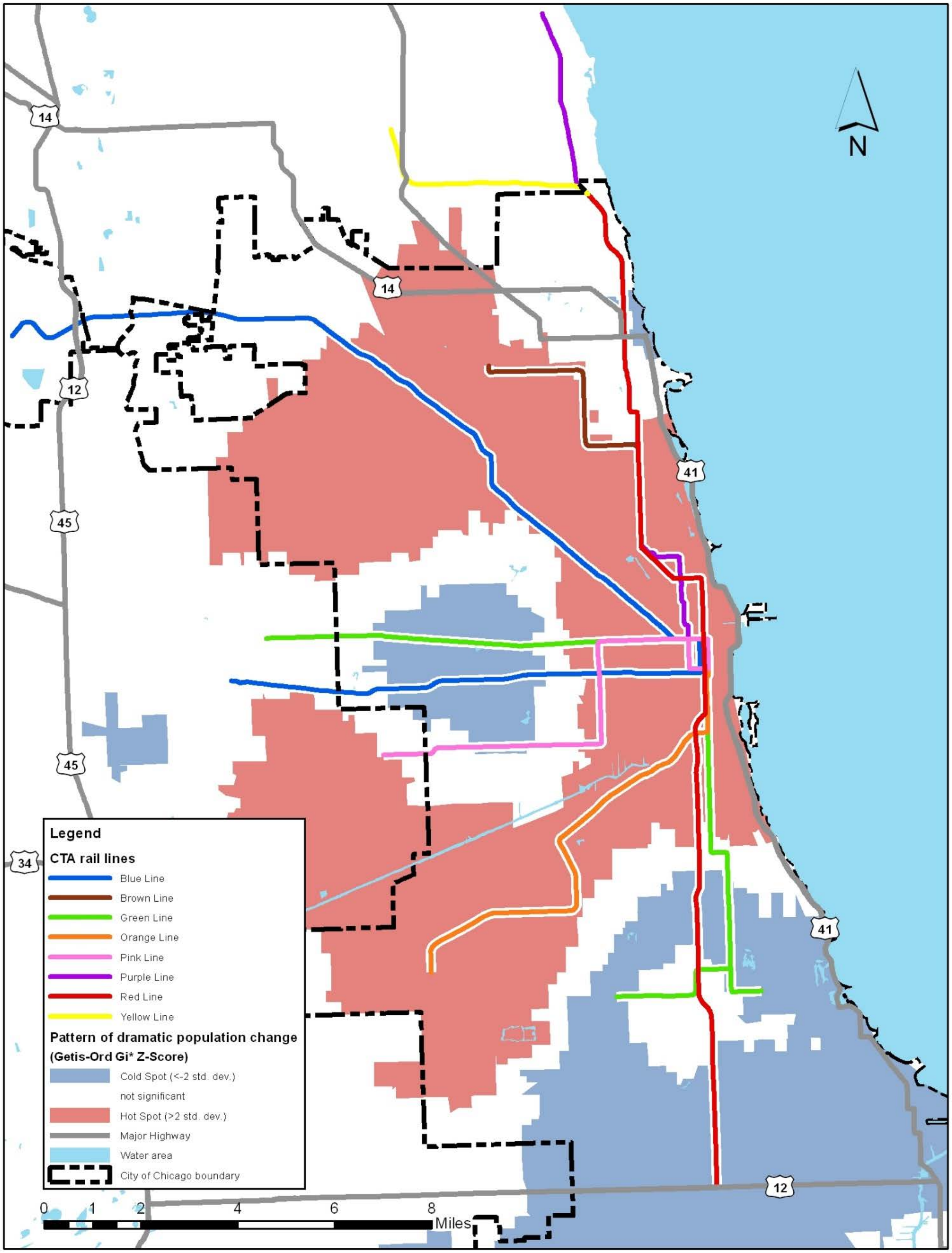


Map 7: Change in housing density by blockgroup in Chicago, 1990-2010

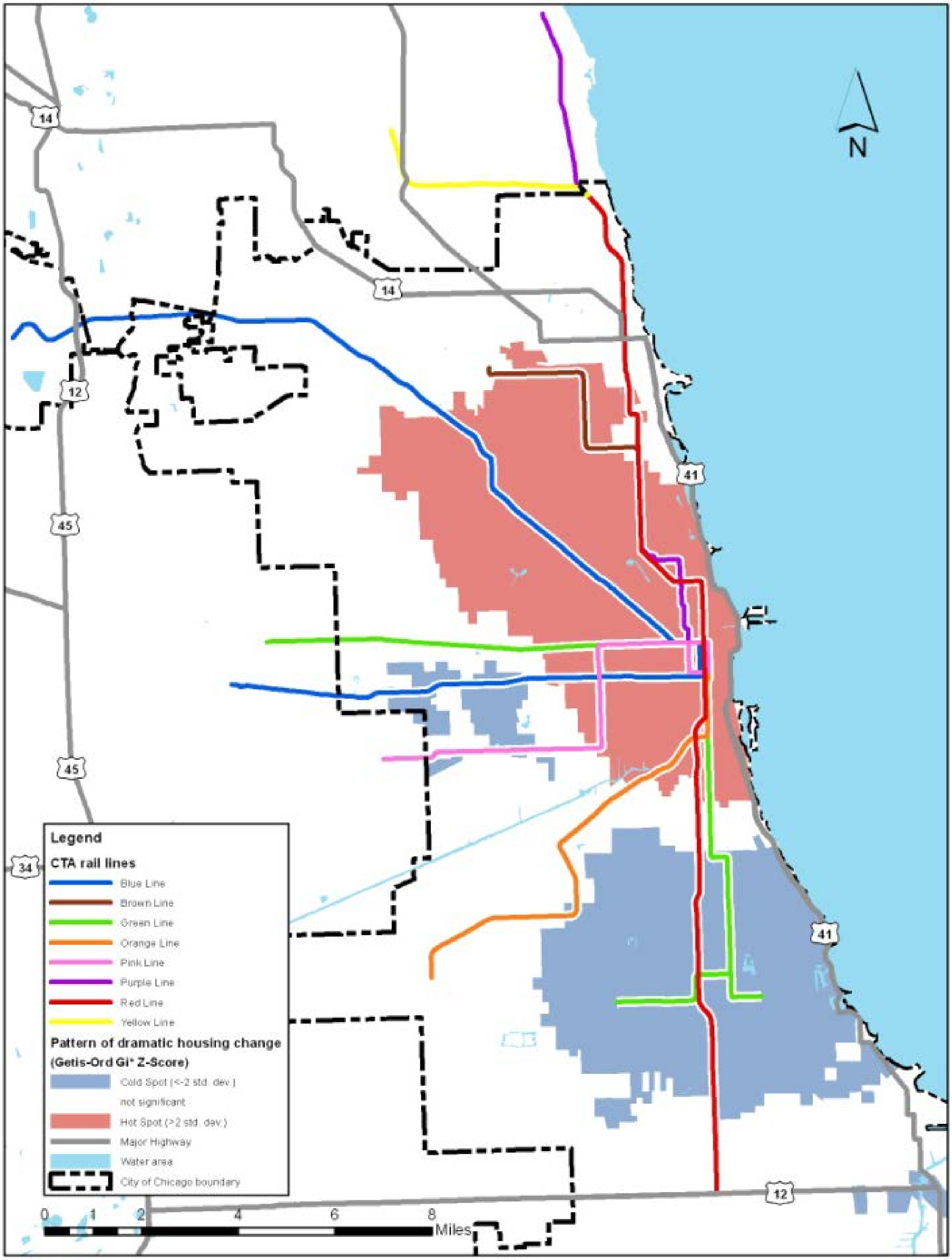
the red areas in Map 6 denote the neighborhoods where density in population has the highest increase from 1990 to 2010, while the blue areas are those where density decreased the most. The areas with the largest population growth are concentrated around Downtown Chicago, the northern suburbs, the west suburbs around the end of the Pink Line, and the southwest suburbs along the Orange Line, the targeted line of this study.

Presented in a similar map symbology, the red areas in Map 7 are those neighborhoods which experienced the highest increase in housing density from 1990 to 2010. Comparing the density change pattern of the neighborhoods surrounding the Orange Line on Map 6 and Map 7, we have the impression that these areas did experience growth in population density, while no big change in housing density is observed. Moreover, the vast majority of the Chicago region experienced little change in housing density. The only exception is the area around downtown, where a significant increase in housing units can be observed. Such a contrast in the patterns of the two maps implies that the effects of the Orange Line might be different on population density and housing density.

To test whether the phenomenon of densification clustering across space is statistically significant, this study uses “Hot Spot Analysis” tool in ArcGIS to continue exploring the spatial pattern of the density change in the region. The goal of hot spot analysis is to identify the presence of clusters of statistically significant density change. As explained in the research design chapter, the Hot-Spot Analysis tool offered by the ArcGIS software calculates the Z-score of each neighborhood among all neighborhoods in the region. Map 8 and Map 9 show the results of hot spot analysis in population and housing density change in the region.



Map 8: Hot-spot analysis of the population density change in the Chicago region, 1990-2010



Map 9: Hot-spot analysis of the housing density change in the Chicago region, 1990-2010

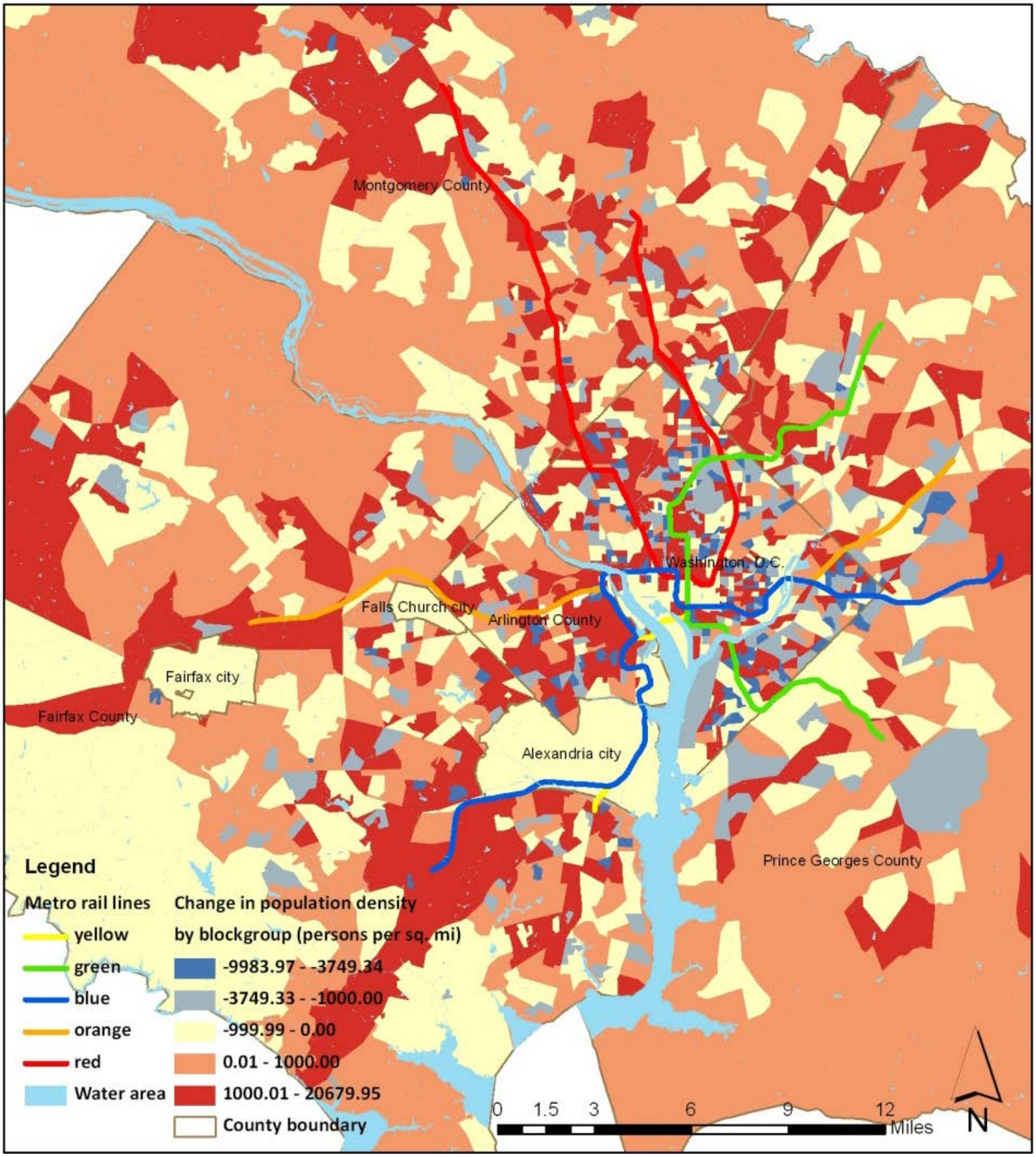
In these two maps, a neighborhood shown in red is a hot spot that has a Z-score of 2 and higher in density change. In other words, these hot spots experienced density changes more than two standard deviations higher than the average level of all neighborhoods in the metropolitan region. By contrast, the blue areas are the cold spots where densification is lower than two standard deviations below the regional average value.

Through this analysis, a simpler, generalized version of the spatial pattern of density change in the Chicago region can be observed on the maps. For example, Map 8 shows that the neighborhoods along the Orange Line are part of the hot spots in population densification, which confirms our earlier impression from Map 6 that these neighborhoods did have significant increase in population density. Meanwhile, Map 9 tells us that the area along the Orange Line is not part of the hot spots in housing densification, which means these is no significant change in housing density. However, it is worth noting that the spatial analysis only presents the densification outcomes without taking other factors into account. There might be other variables that also affect density change. In other words, what we observed—the significant population densification along the Orange Line and the missing housing densification in the same area from 1990 to 2010—are not necessarily the outcomes of the opening of the Orange Line. To provide sufficient evidence on the causal relationship between the new rail service and area densification, as described in the research design chapter, we will apply a DID method with multivariate analysis to quantify and single out the impact of the Orange Line from other factors. The results of such analysis will be presented in Chapter 6.

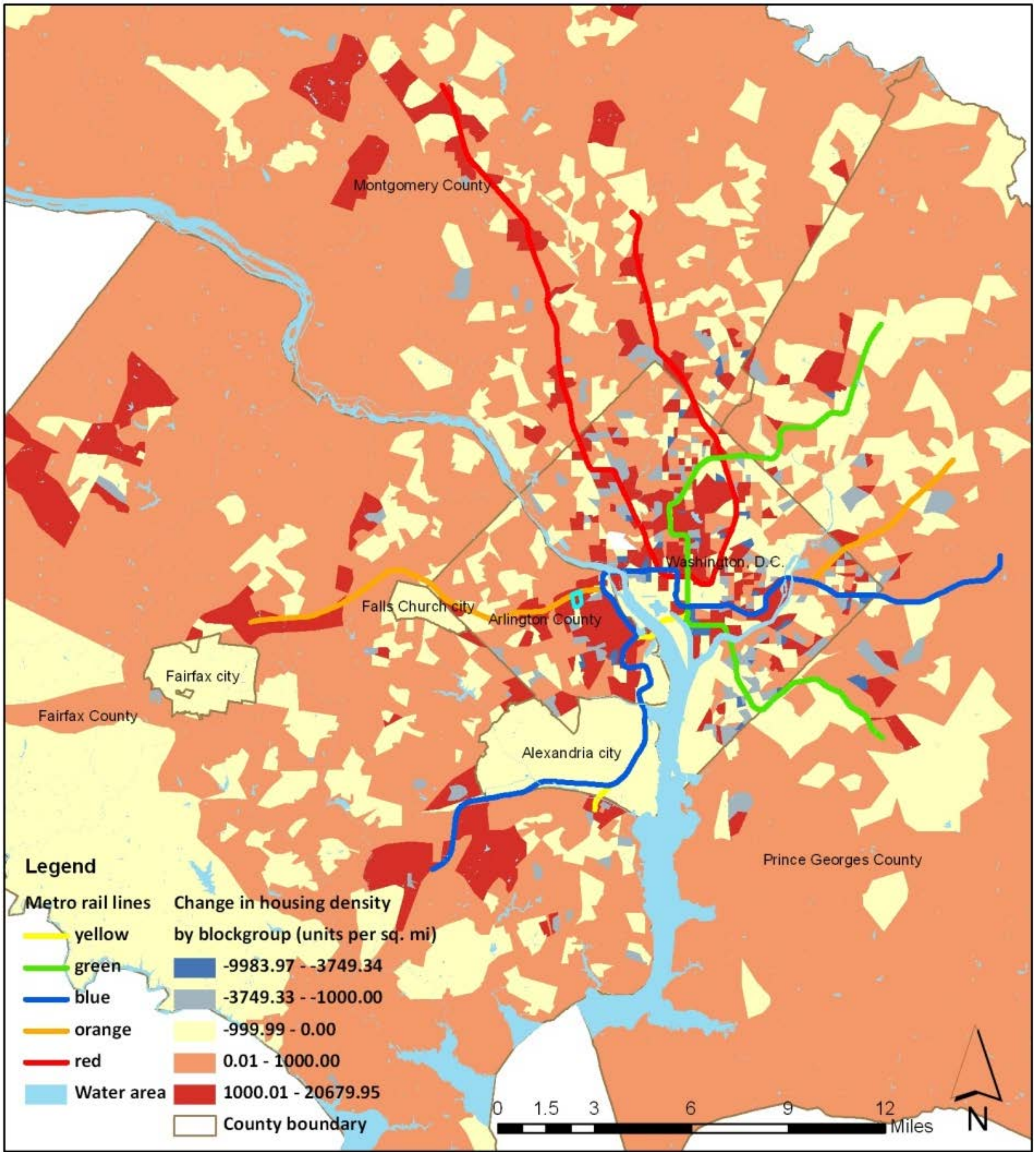
5.2 Washington, D.C.

Using the same techniques, we make the map of the density change in population by blockgroup (Map 10) in the Washington, D.C. region shows that the most area of the region experienced increase in population density between 1990 and 2010. However, no clear spatial clustering of population densification can be detected from these maps. Meanwhile, the housing densification (Map 11) is more concentrated to downtown and around the termini of the Red, Orange and Blue Lines.

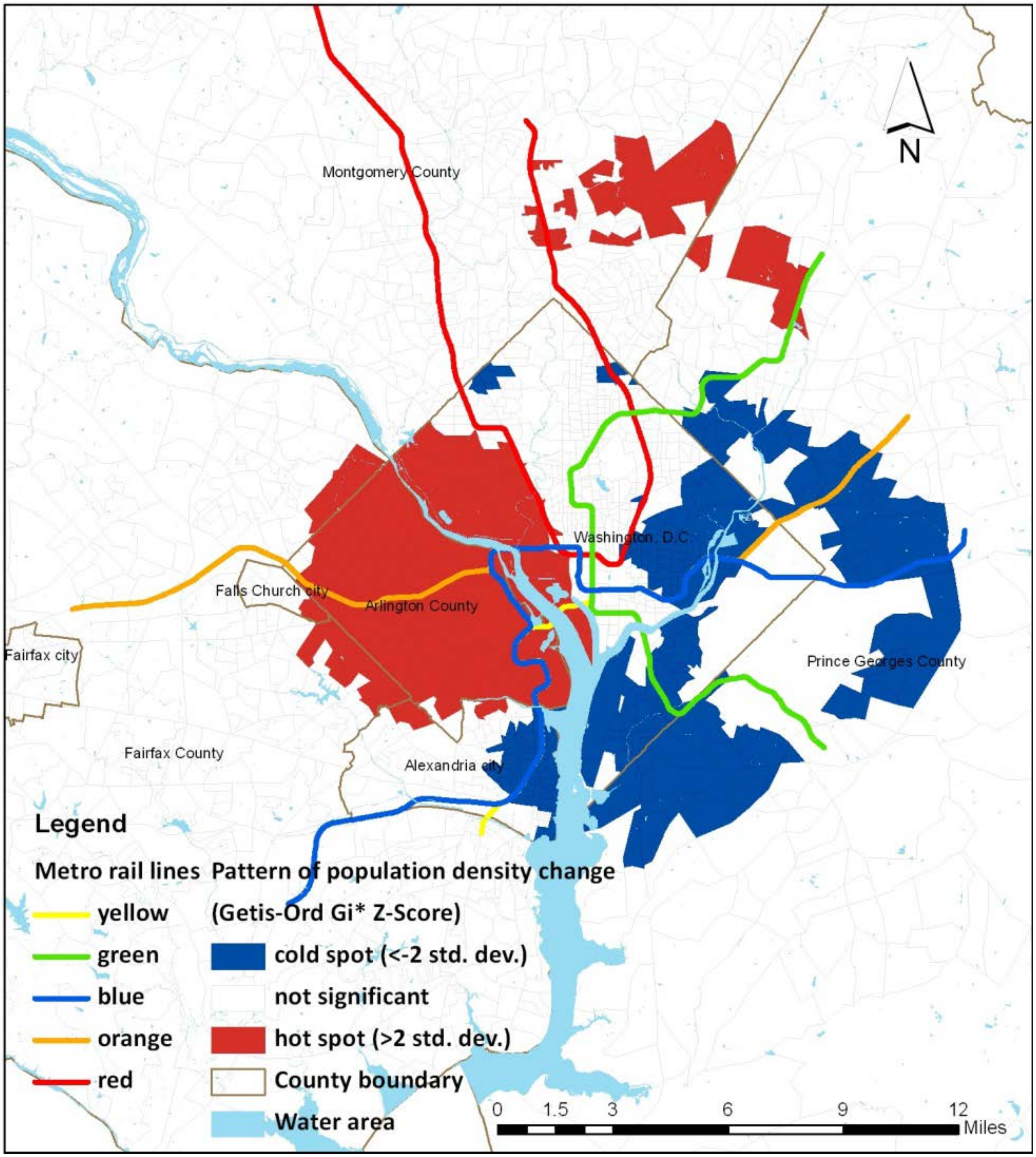
The results from hot spot analyses (Map 12) reveal that the most dramatic increase in population density happened in the Arlington County of Virginia and its vicinity area. South and East corners of DC and the bordering area of DC and the Prince George County experienced serious decline in population density. The hot spot analysis of housing density change (Map 13) shows a similar pattern, except that the housing density increases in a statistically significant way in the entire part of DC to the north of the Washington River. Although the south segment of the Green Line seems to be located where densities declined, a more thorough analysis is needed before any conclusion on the connection between the Green Line and the densification outcomes is established. As we should be reminded before, the spatial analysis only presents the densification outcomes and does not provide evidence on causalities.



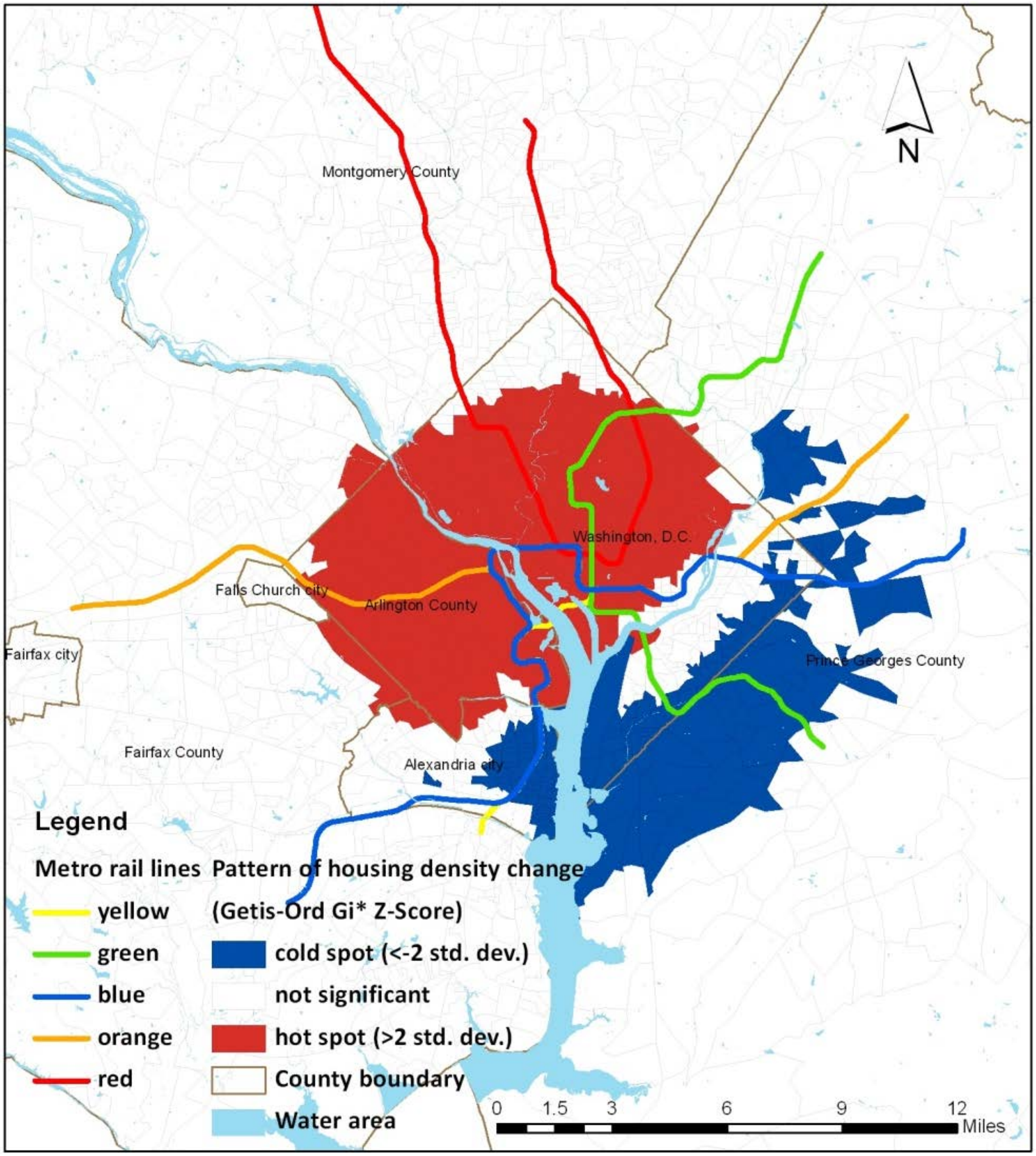
Map 10: Change in population density by blockgroup in Metropolitan Washington, 1990-2010



Map 11: Change in housing density by blockgroup in Metropolitan Washington, 1990-2010



Map 12: Hot-spot analysis of the population density change in Metropolitan Washington, 1990-2010

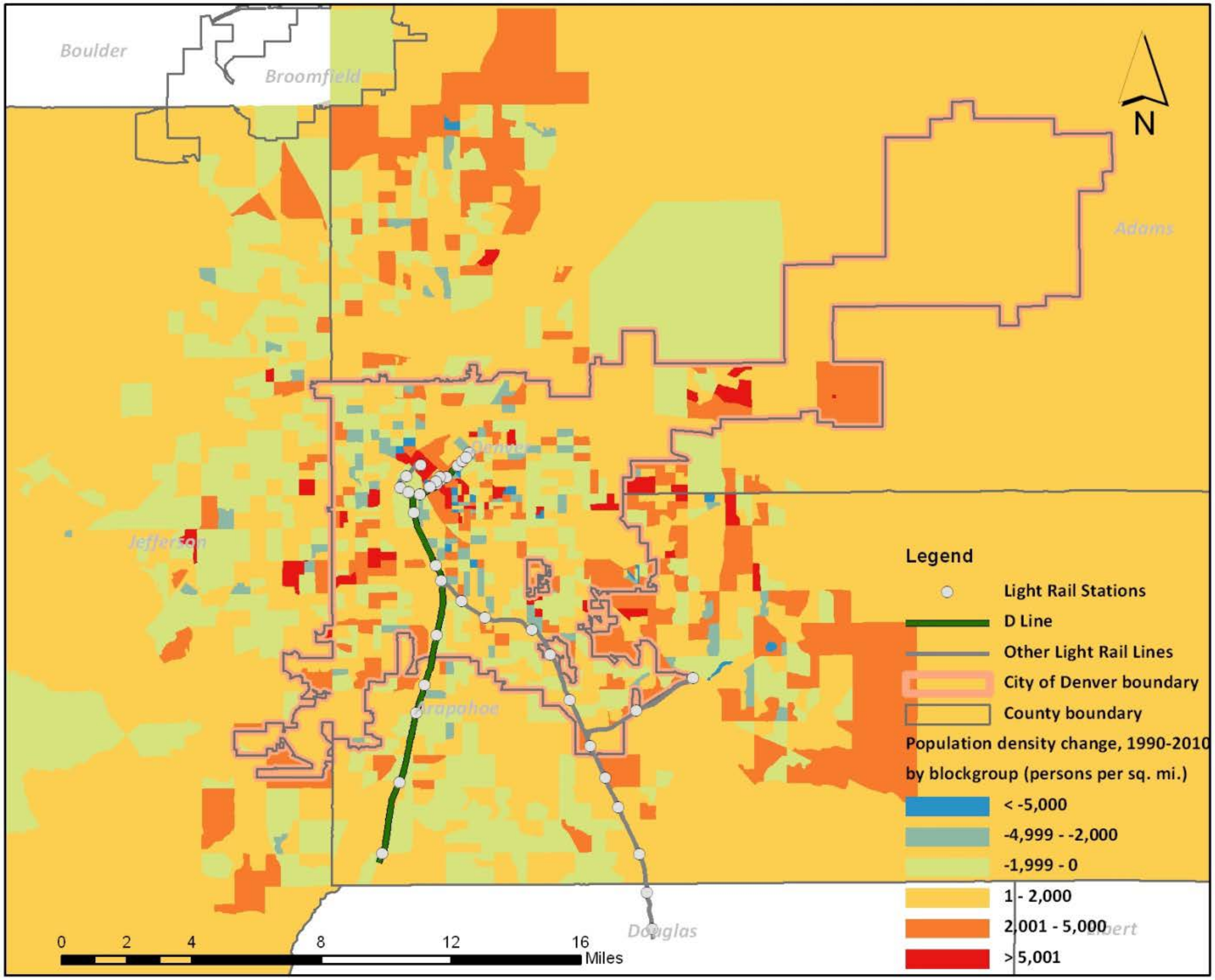


Map 13: Hot-spot analysis of the housing density change in Metropolitan Washington, 1990-2010

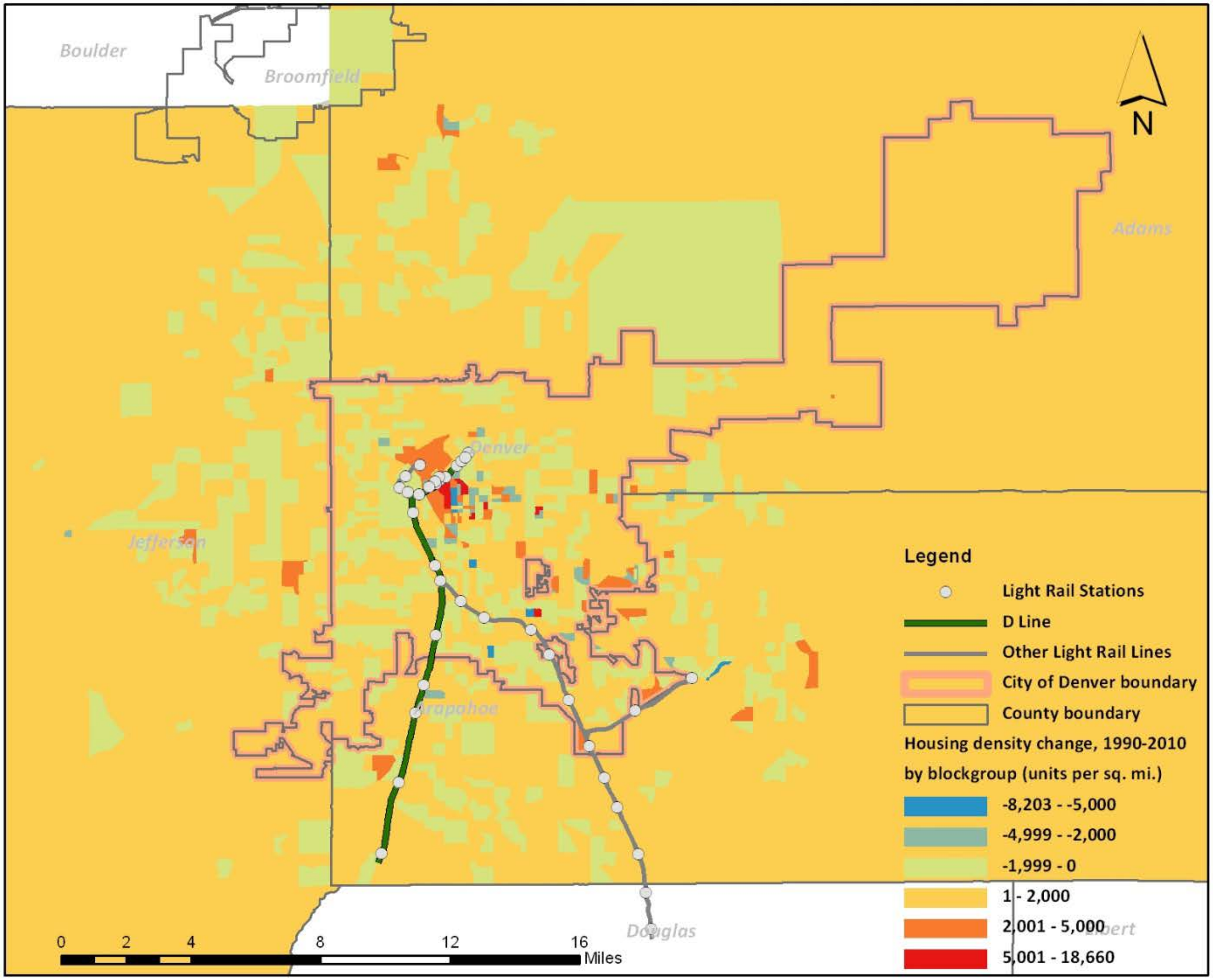
5.3 Denver

The spatial analysis of the densification effects of the D Line in Denver starts with mapping the density change in the Denver region served by the LRT system. From the two maps shown below (Map 14 and Map 15), there is no particular densification pattern detected along the D Line. Population densification shows a fairly random pattern, while the largest increases in housing density seem to be concentrated at the center of the City of Denver.

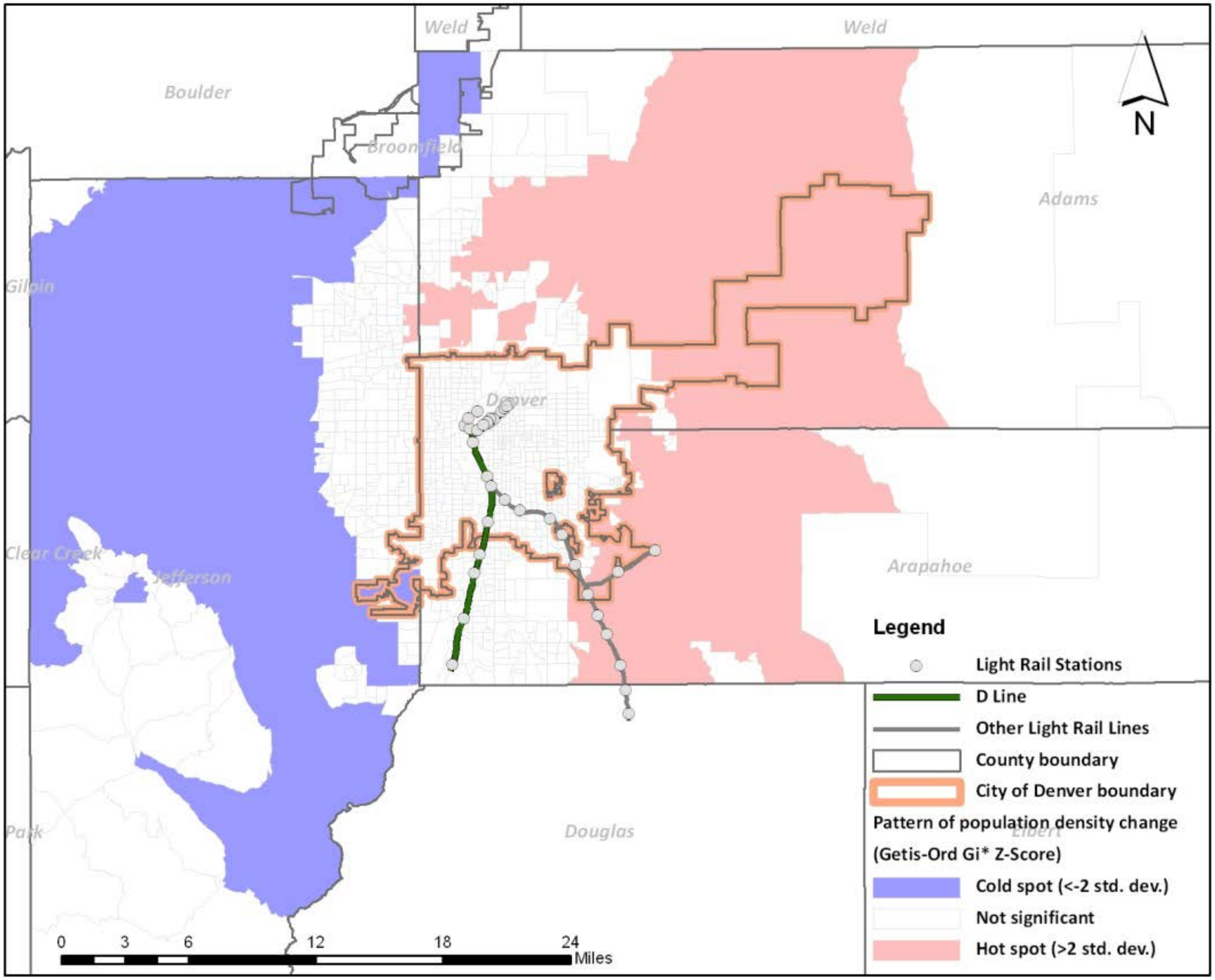
Similar to what has been done to the Chicago and Washington cases, hot spot analysis tools are used to detect areas of significant change in densities. The results are quite informative (Map 16 and Map 17). Map 16 shows that the growth in population density was polarized in two parts, mostly outside of the City of Denver—the east suburbs gained lots of population while the west suburbs lost a large amount of residents. By contrast, Map 17 shows that the housing density has no statistically significant change in any particular area in the entire metropolitan region. In other words, the hot spot analysis result of housing density change yields no hot or cold spot; therefore, the entire map is in blank color—showing no blue or red area. In both cases, the neighborhoods along the D Line experienced no significant change over the twenty-year period—1990 to 2010. However, as emphasized in the previous two cases, a multivariate analysis is needed before we conclude on the causality between the D Line and area densification.



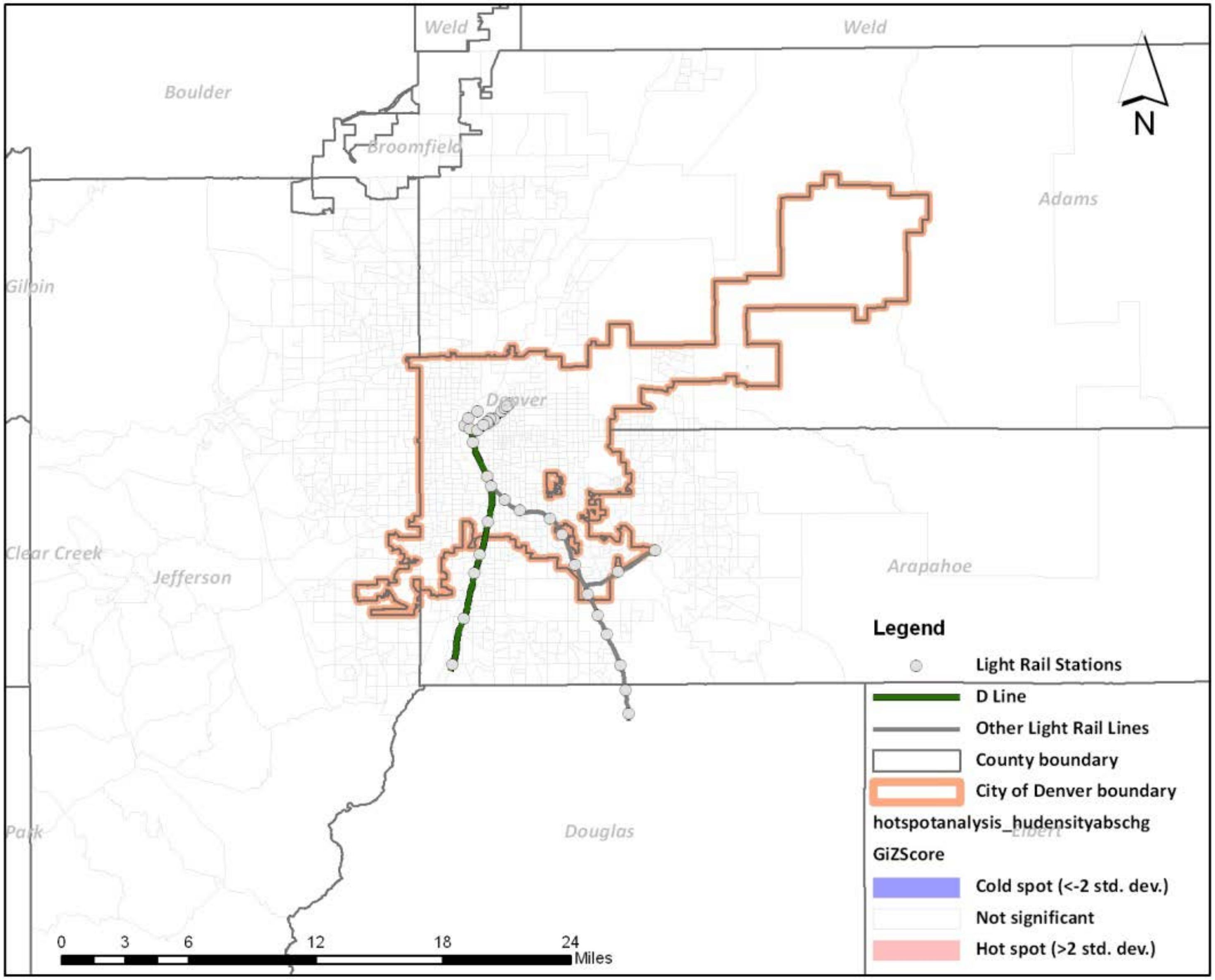
Map 14: Change in population density by blockgroup in the Denver region, 1990-2010



Map 15: Change in housing density by blockgroup in the Denver region, 1990-2010



Map 16: Hot-spot analysis of the population density change in the Denver region, 1990-2010

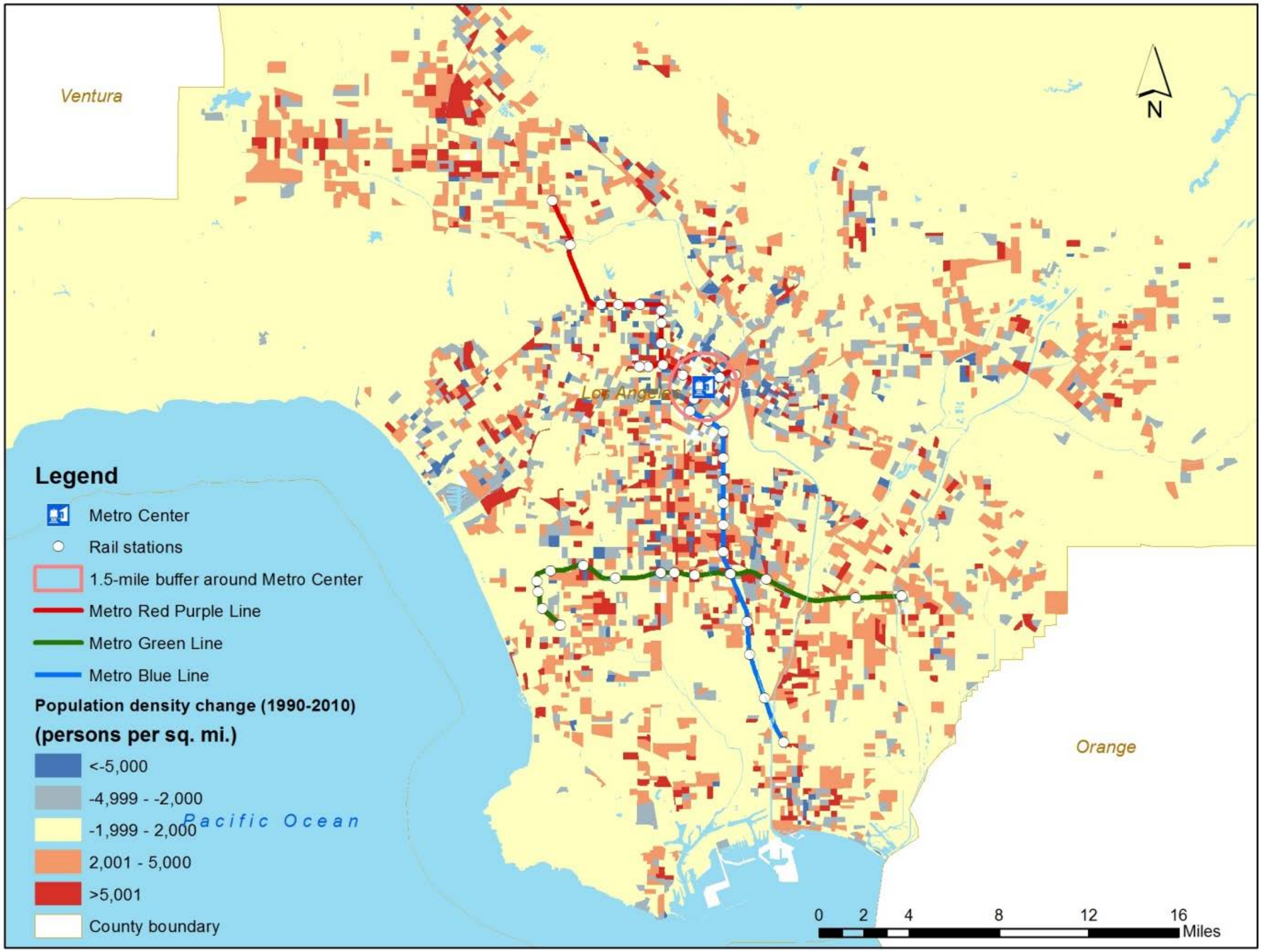


Map 17: Hot-spot analysis of the housing density change in the Denver region, 1990-2010

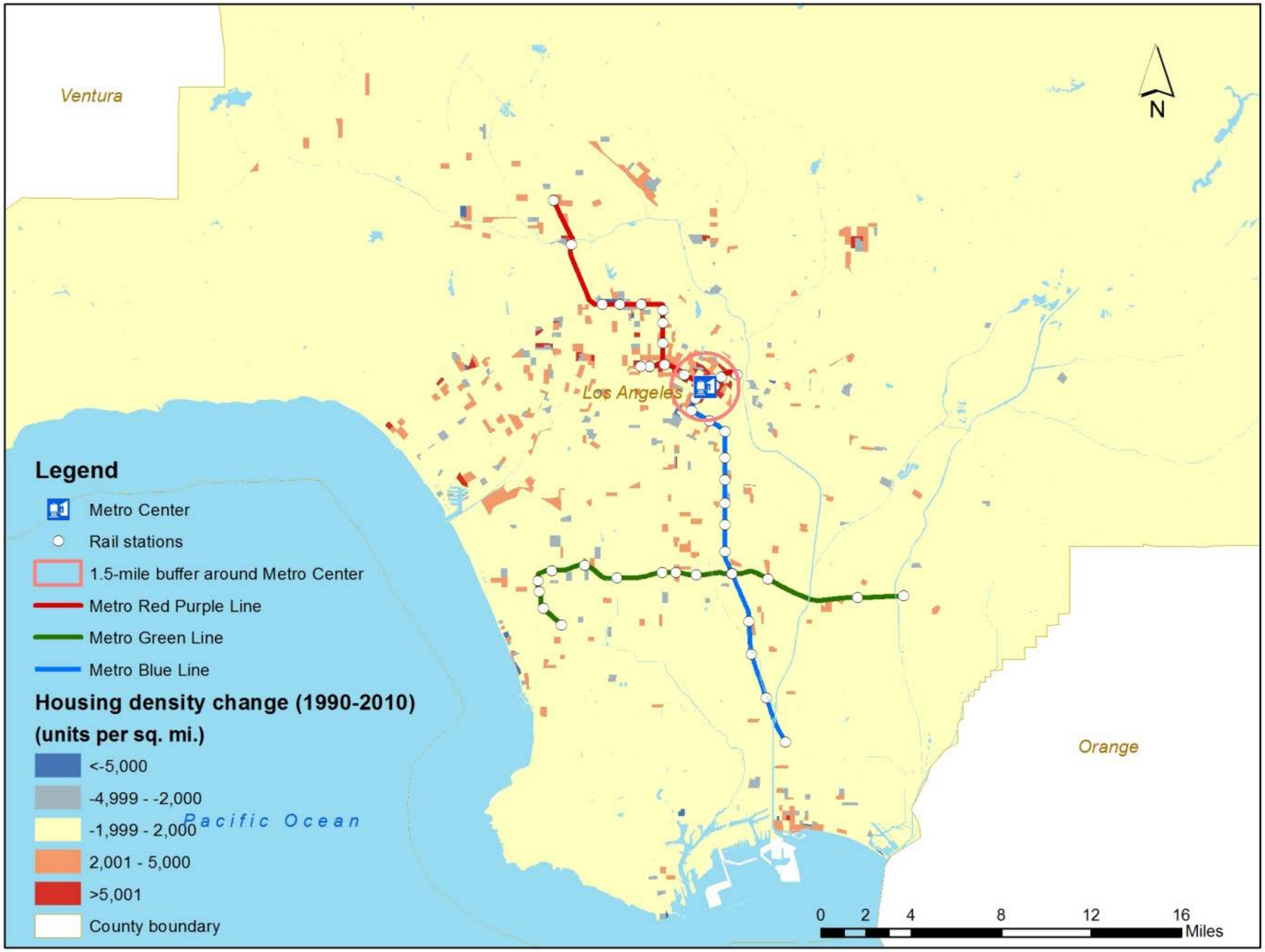
5.4 Los Angeles

The map of the density change in population by blockgroup in the Los Angeles region (Map 18) shows a mosaic pattern of increased density and decreased density mixed all over the region. Although there is no clear spatial clustering of population densification, neighborhoods with the greatest density change seem to line up with rail transit corridors, including two of the targeted lines of this study: the Blue and the Green Line. The spatial pattern of housing density change in the Los Angeles region (Map 19) shows is no big change across the entire metropolitan area. For the twenty years from 1990 to 2010, the housing density of the most part of the region keeps almost unchanged, except for several small areas dispersed on the map showing increases (Red) or decreases (blue) in density.

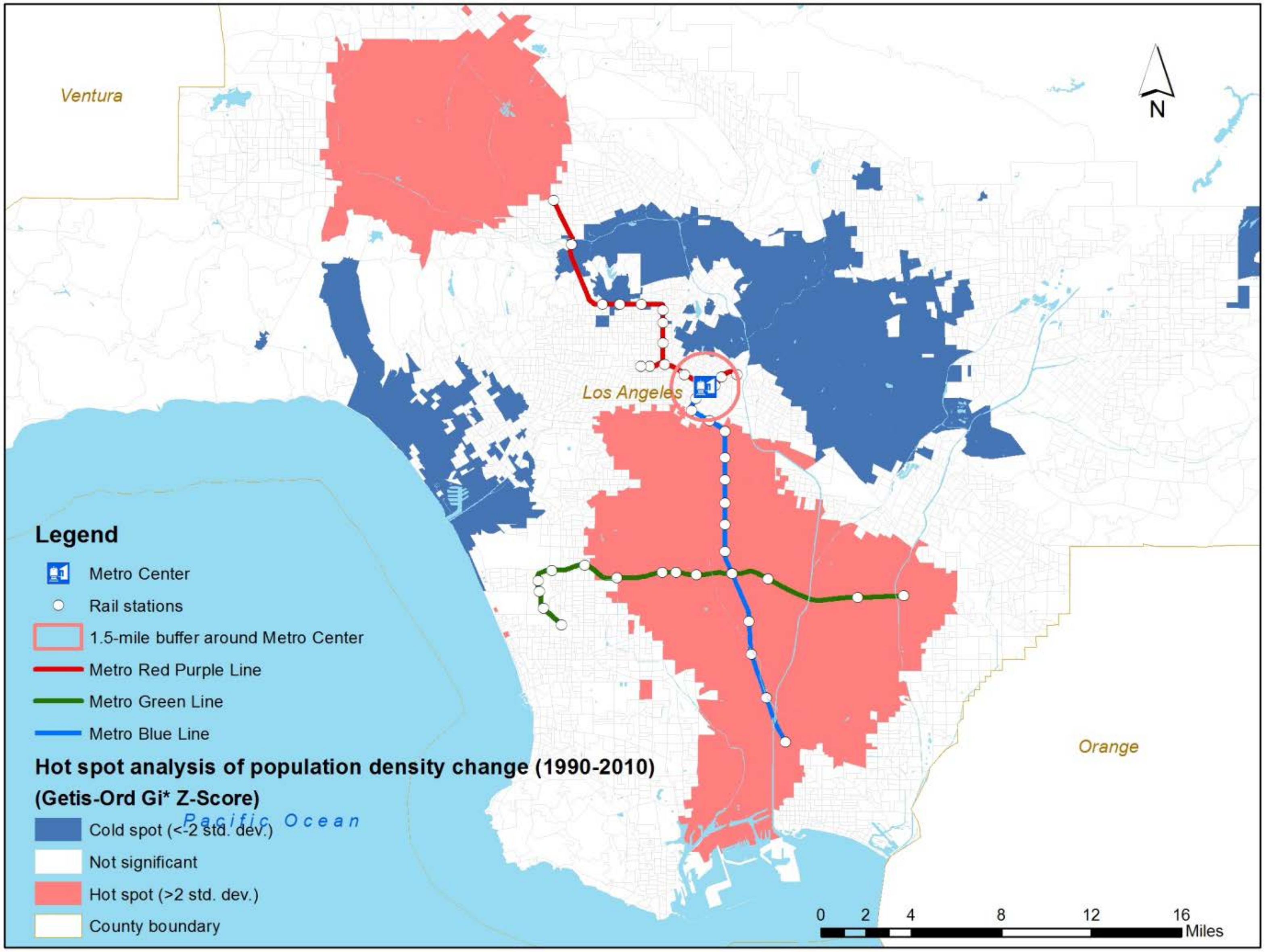
The hot spot analysis shows some promising possibilities of densification in both population and housing along the targeted rail Lines. Map 20 shows that the neighborhoods along the Blue and Green Lines are part of the hot spots where the largest increases in population density are concentrated. Map 21, which presents the results of hot spot analysis of housing densification, shows that the neighborhoods around most part of the Red and Blue Lines experienced the largest increase in housing density over the 20-year period. Although we cannot infer from these observations that the rail lines caused the area densification, these illustrations at least show the spatial association between large densification and the locations of new rail lines.



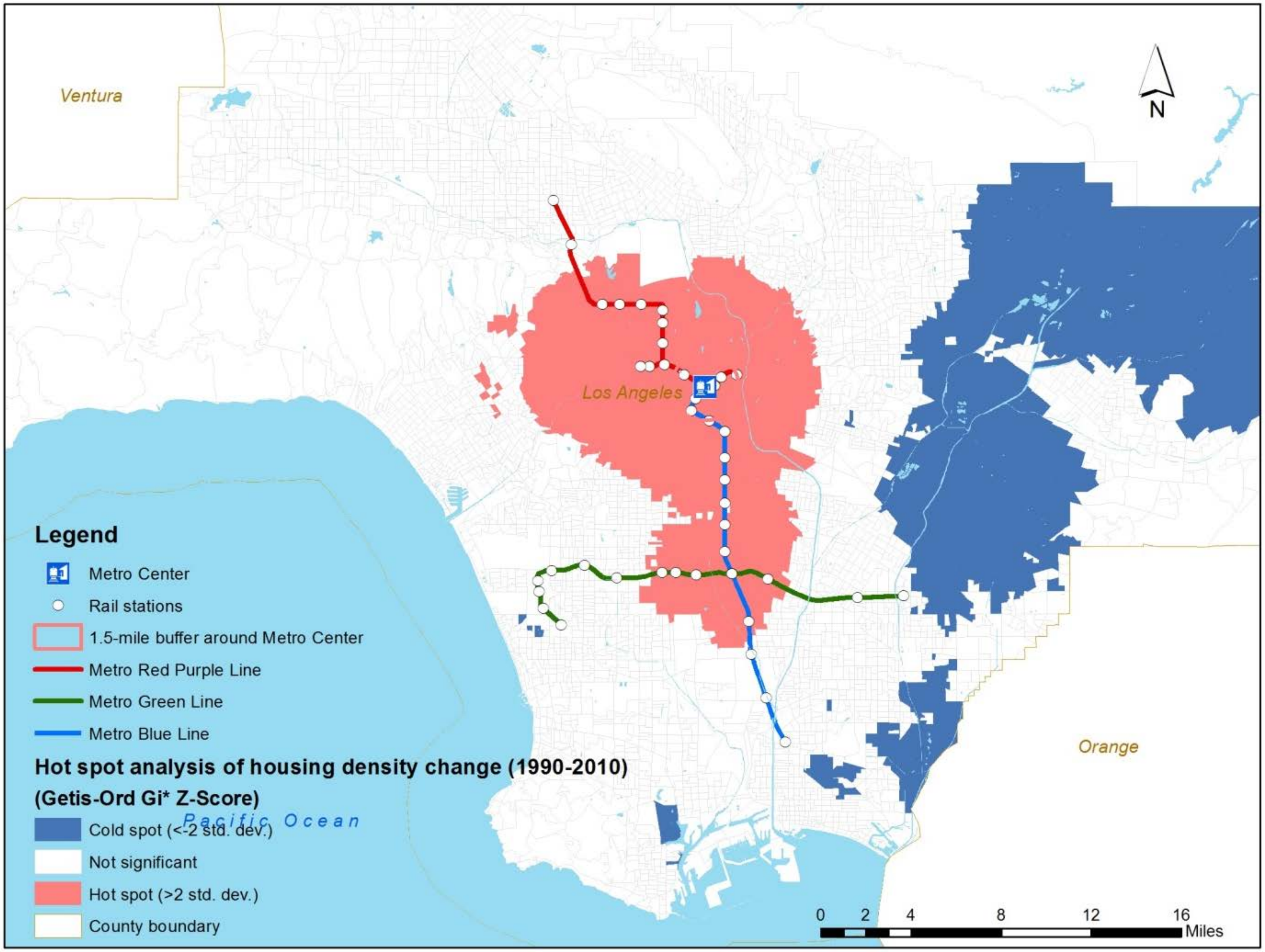
Map 18: Change in population density by blockgroup in the Los Angeles region, 1990-2010



Map 19: Change in housing density by blockgroup in the Los Angeles region, 1990-2010



Map 20: Hot spot analysis of the population density change in the Los Angeles region, 1990-2010



Map 21: Hot spot analysis of the housing density change in the Los Angeles region, 1990-2010

Summary of spatial analysis

Investigating the spatial pattern of density change in the region is the first step taken to analyze the densification effect of the new rail transit lines under study. For each case region, thematic maps of the change in population density and housing density are made to visualize the general densification trend. These maps help us identify the spatial pattern of densification across the region. Based on the thematic maps of densification trends, this study continues with hot spot analysis to figure out if there are spatial clusters of densification that is statistically higher or lower than the rest of the region. The resulting maps of hot spot analysis assists us to observe if there is higher densification near the newly constructed urban rail transit lines and stations than in other neighborhoods.

To sum up the findings from the spatial analysis described in this chapter, the spatial pattern of density change from 1990 to 2010 in the four case regions are as follows. In Chicago, there is notable densification of population along the Orange Line, the line under study, but the densification of housing does not show any association with urban rail lines. In Washington, D.C., densification of both population and housing is concentrated within the District and its close vicinity. We did not observe any spatial association between the Green Line, the line under study, and the densification of population and housing in the region. In Denver, the densification of population and housing shows a random pattern across the metropolitan area, therefore we could not associate the densification with the D Line, the line under study, or any particular fixed landmark in the region. In Los Angeles, most parts of the area along the lines under study show high levels of population and housing densification.

Even in the cases where we observe a spatial association between densification and the locations of the rail lines under study, it does not suggest any causation, because there might be other variables that also affect density change. To provide sufficient evidence on the causal relationship between the new rail service and area densification, as described in the research design chapter, we will apply a DID method with multivariate analysis to quantify and single out the impact of the rail lines from other factors. The results of such analysis will be presented in the next chapter.

Chapter 6: Regression analysis: the densification effects and the interferences of contextual factors

The previous findings on spatial analysis yields visualization of the densification patterns across space. Now we have a sense of the spatial patterns of densification in each of the case regions, we can proceed with quantifying the densification effects of the targeted rail lines. This chapter presents the findings from the regression analysis with the difference-in-differences design proposed in Chapter 3. For each case region, we first present the actual neighborhoods in the treatment and control groups selected for the analysis. Then we compare the density change in the two groups and the descriptive statistics of the variables that are considered in the models. Lastly, the regression results on the best-fitted models are introduced and explanations are given. These findings shed light on the densification effects of urban rail transit and how the neighborhood factors may affect the densification effects.

6.1 Chicago

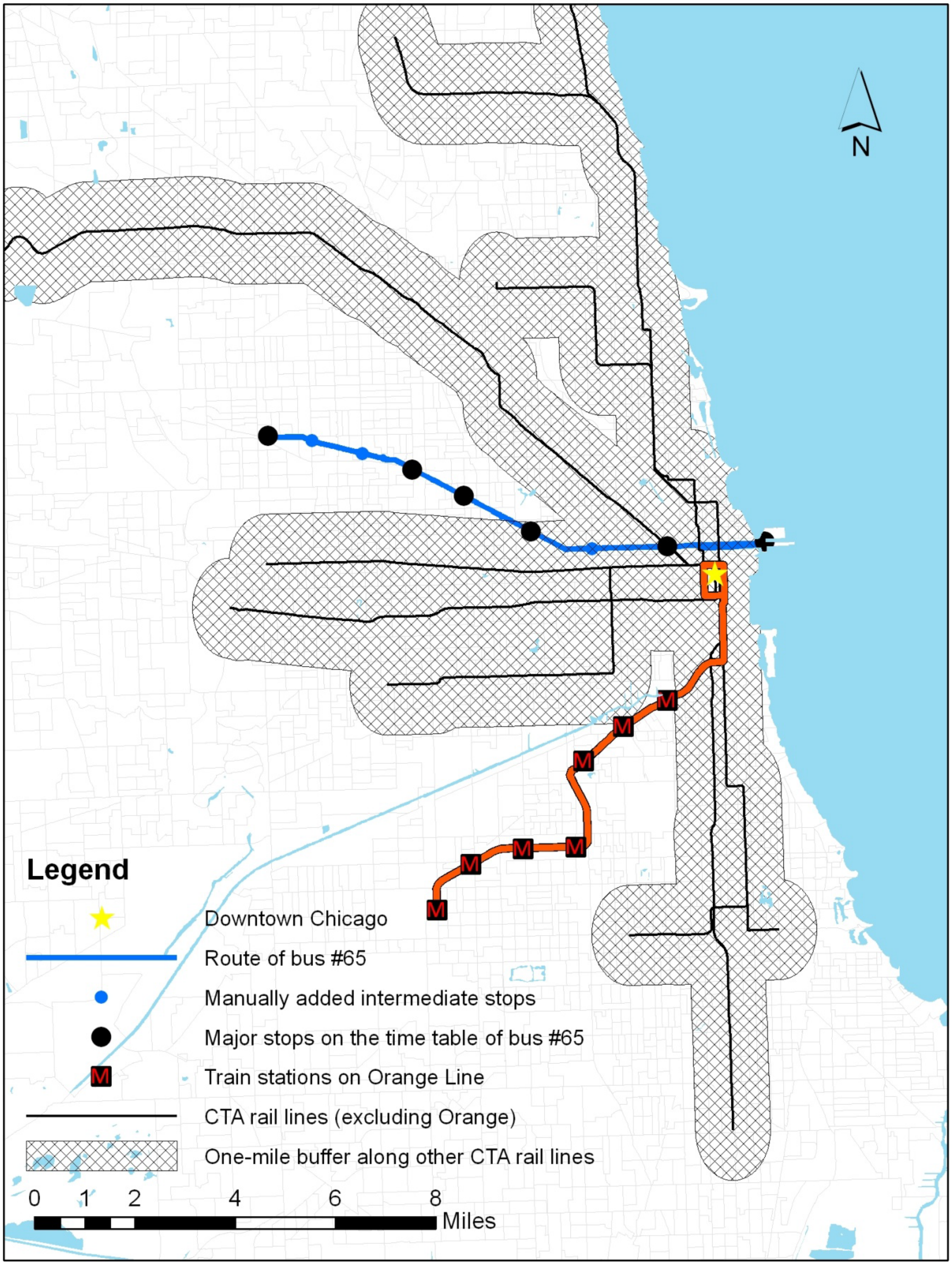
1) Sample selection

The most crucial step in using DID design to evaluate the causality between new rail transit investments and neighborhood densification is to identify the control group—neighborhoods that serve as the counterfactuals of the treatment neighborhoods. As described in the research design chapter, this study used two different ways to define the "treatment" effect of urban rail transit and constructed two sets of models accordingly—the corridor models and the node models.

By the definition of corridor models in the research design of this study, neighborhoods located within a half mile along the *route* of the lines under study formed the treatment group.

The control group, by contrast, consisted of neighborhoods located within a half mile from the selected bus lines. These bus lines served as the counterfactuals of the lines under study. The selection process of the counterfactual bus lines applied three criteria. First, the bus lines should run in the same direction and through similar urban forms as the lines under study. Second, the bus lines shall be outside of a half-mile buffer zone of all the rail transit lines in the area, to prevent any development impact caused by rail lines. In the case of Chicago, only bus #65 meets these two criteria and becomes the only counterfactual route of the Orange Line.

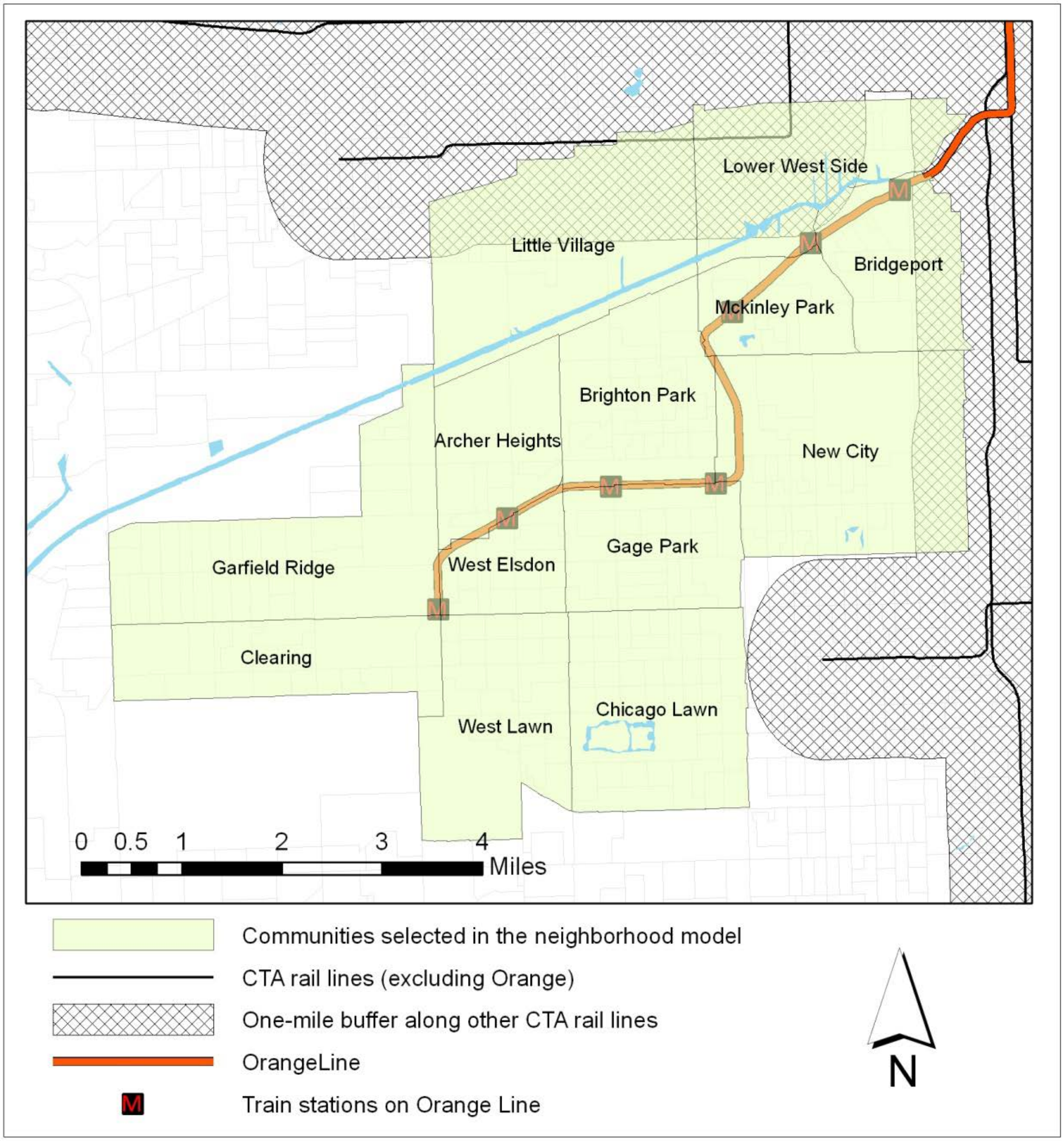
The node model is built upon the corridor model with a further criterion that only the neighborhoods located within a half mile from the *stations* on the lines under study made the treatment group. The control group only contained neighborhoods within a half mile from selected bus stops on the counterfactual bus line in the corridor models described above. The selection of these counterfactual bus stops followed two steps. First, the major stops listed on the time table of the counterfactual bus lines were first candidates. The rationale was that these stops which made to the time table should be important nodes along the route, thus sharing similar location significance as the rail stations on the lines under study. Second, a four-to-six-minute spacing rule was applied to ensure that these counterfactual bus stops would have similar spacing as the rail line stations. Where the travel times from one bus stop to its two neighboring stops are both shorter than four minutes, this stop will be deleted. Where the travel time between two neighboring major stops was longer than eight minutes, an intermediate bus stop will be added. After these two steps, the counterfactual bus stops were finalized and the neighborhoods in the control group were identified accordingly (Map 22).



Map 22: The Orange Line and the counterfactual bus line/stops in Chicago

As Map 22 shows, the corridor model and the node model have the control groups defined based on the only selected counterfactual bus line #65, which runs from downtown Chicago towards the northwest suburb—a completely different geographic area than the neighborhoods that Orange Line serves. Due to historic reasons, South Chicago neighborhoods are overall much different than North Chicago neighborhoods in terms of such dimensions as demographics, income, and housing stock (Maly, 2000). Therefore, using neighborhoods in the north side as the control group for the neighborhoods in the south side may lead to bias in the analysis results on the densification effects.

To avoid the bias caused by the differences between the north and the south parts of the city, for the specific case of Chicago, this study also constructed a third model—the neighborhood model to measure the impacts of the Orange Line on density. In the neighborhood model, the treatment group is defined in the same way as in the corridor model, while the control group is defined as the neighborhoods located in "vicinity communities" but farther than half a mile from the Orange Line. Using vicinity as the criterion to construct control and treatment groups is a common practice in many previous studies that evaluated the neighborhood impacts of rail transit projects (Bollinger & Ihlanfeldt, 1997; Bowes & Ihlanfeldt, 2001; Cervero & Landis, 1997; Gatzlaff & Smith, 1993; Hass-Klau, Crampton, & Benjari, 2004; Hess & Almeida, 2007; Landis, et al., 1995; Litman, 2004; A. C. Nelson, 1992; Parsons Brinckerhoff, 2001). Here in the case of the Chicago, vicinity communities include the following (in the order of geographic location, clockwise from the northeast corner of the area): Lower West Side, Bridgeport, McKinley Park, New City, Gage Park, Chicago Lawn, West Lawn, Clearing, Garfield Ridge, West Elsdon, Archer Heights, Brighton Park, and Little Village, as shown in Map 23.



Map 23: The selected communities in the neighborhood model of the Orange Line case in Chicago

If the wealthier northern part of Chicago led to more densification than the southern part, we would have underestimated the densification effects of the Orange Line using the corridor and the node models. In other words, these two models would yield attenuation bias.

However, we may also have attenuation bias from the neighborhood model constructed here if the actual impact range of the Orange Line is farther than a half mile from the line. In any one of the three models, if we did observe densification effects, the actual magnitude of the effects would be even larger than our estimates.

2) Mean comparison

Now that the control groups and the treatment groups are assigned, we can first compare the population and housing density trend in those groups (Figure 6 and Figure 7) before applying the regression analysis to estimate the densification effects or the Orange Line.

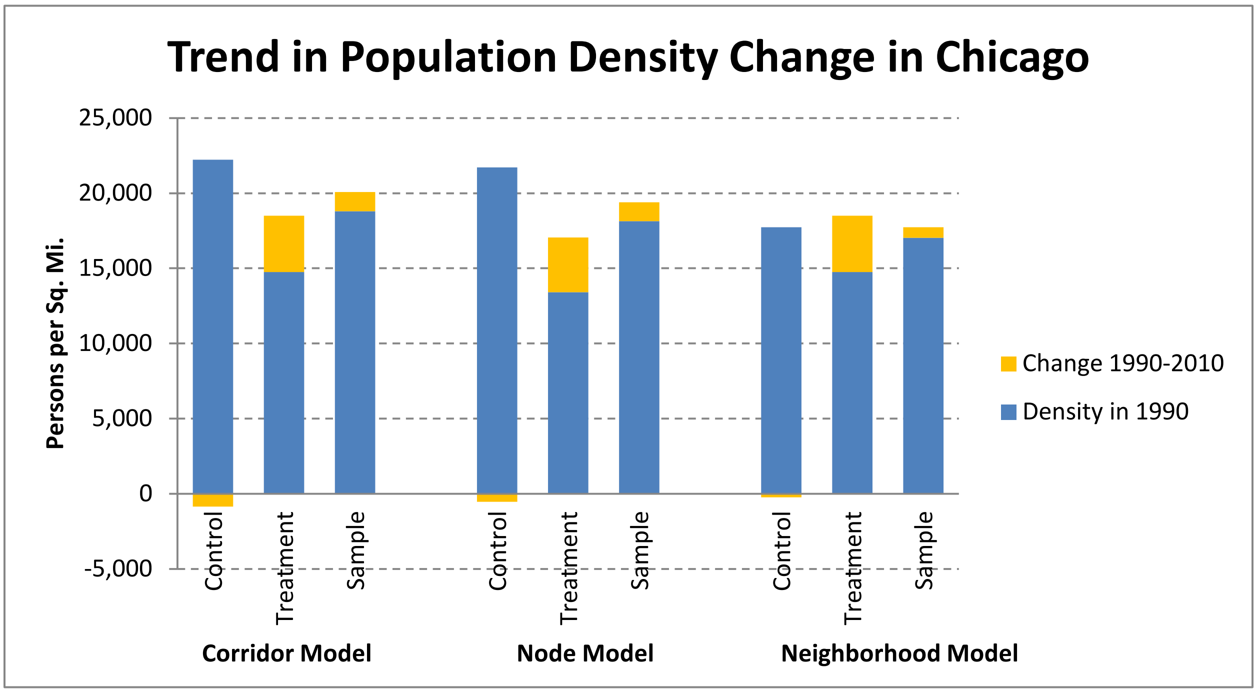


Figure 6: Comparison of the population density change in control and treatment groups of the three models, the case of Chicago Orange Line, 1990-2010

Figure 6 shows a clear pattern that the treatment groups experienced more increase in population density than the control groups, in all three different models. By contrast, Figure 7 shows that the housing density change did not vary much between the control groups and treatment groups in the corridor and node models. Only a slightly higher housing densification presents in the treatment group than the in the control group of the neighborhood model. These observations are consistent with our previous findings from the hot spot analysis.

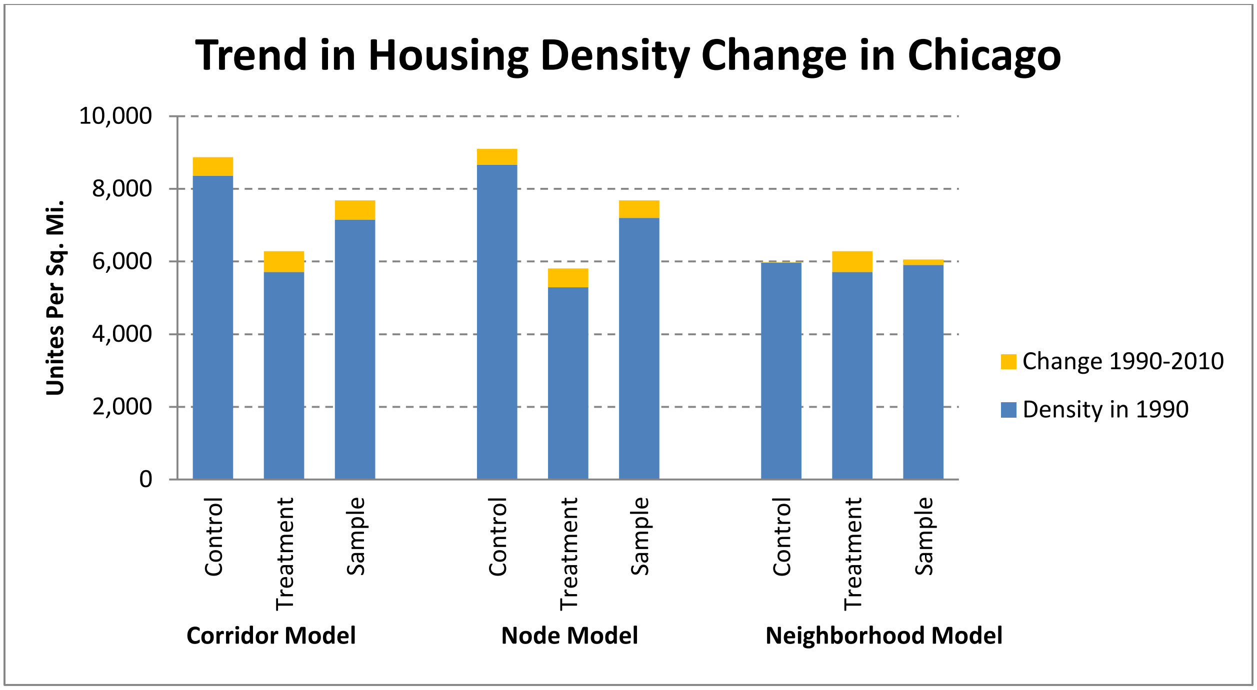


Figure 7: Comparison of the housing density change in control and treatment groups of the three models, the case of Chicago Orange Line, 1990-2010

3) Regression results

To carry out the regression models proposed in Chapter 3, this study uses the SPSS software to test different models and find the best-fitted ones according to the procedures described in Section 3.4, Part II(3). The models start with a rich set of variables that fall in four categories: treatment dummies, station features, neighborhood factors (including geographic features and socio-economic features), and the interaction terms between treatment dummies and neighborhood factor variables. The descriptive statistics of these variables are presented in Table 4.

Table 4: The descriptive statistics of the variables in the regression models, the Chicago case

Variable	Unit	Valid cases	Range	Minimum	Maximum	Mean	Std. Deviation
Dependent variables							
Change in population density, 1990-2010	persons per square miles	342	46671.35	-29742.53	16928.82	708.76	7386.06
Change in housing density, 1990-2010	units per square miles	342	18040.11	-10141.54	7898.57	152.42	1771.72
Station features							
Distance from downtown	miles	342	9.37	1.99	11.36	6.88	2.17
Fare to downtown by rail transit	2010 Dollars	342	0.00	2.25	2.25	2.25	0.00
Total parking spots	spots	342	390.00	0.00	390.00	202.58	116.96
Age of the station as of 2010	years		0.00	20.00	20.00	20.00	0.00
Accessibility to jobs by transit		342	411764.60	0	411764.60	32423.37	69927.60
Pre-project neighborhood conditions in 1990							
Population density	persons per square miles	342	75644.20	641.97	76286.17	17023.35	9996.19
Housing density	units per square miles	342	20289.32	108.45	20397.77	5904.73	3063.95
Total population	persons	342	5499.00	116.00	5615.00	1069.10	536.25
Total number of housing units	units	342	932.00	46.00	978.00	368.62	141.70
Percentage of African-Americans		342	1.00	0.00	1.00	0.12	0.28
Percentage of non-citizens		342	0.74	0.00	0.74	0.15	0.13
Unemployment rate		342	0.47	0.00	0.47	0.10	0.08
Poverty rate		342	0.73	0.00	0.73	0.15	0.14
Average household income	1989 Dollars	342	62466.00	12240.00	74706.00	31587.66	7382.45
Number of detached single family housing units	units	342	487.00	0.00	487.00	143.42	103.00
Median value for specified owner-occupied housing units	1989 Dollars	337	138101.00	14999.00	153100.00	62489.31	18524.84
Average gross rent for specified renter-occupied housing units	1989 Dollars	335	630.00	195.00	825.00	426.54	79.79
Housing vacancy rate		342	0.32	0.00	0.32	0.06	0.05

The “stepwise” method is used to filter the independent variables and keep only the ones that are at least statistically significant at the 0.10 level in each model. To make the coefficients comparable between the corridor and node models as well as population and housing densification models, this study synthesizes all four models for each case region and constructs a composite model structure that contains all the independent variables that are statistically significant in at least one of the four sub-models.

The regression results from the models on population density are presented in Table 5. Panel A reports the results from the corridor model; Panel B reports the results from the node model; Panel C reports the results from the neighborhood model. The results show that “being within a half mile from either the station or the route of the Orange Line” (Variable T1) is only marginally significant (at 0.10 level) in having a direct impact on increasing population density in the nearby neighborhoods. Nevertheless, the signs of the coefficients on this variable are all positive. While being even closer (within a quarter mile from the Orange Line) seems to lead to less population densification, the coefficient is not statistically significant. This suggests that the Orange Line did not present significant nuisance effect in close-by areas.

In terms of the interaction terms, all three models report that the interaction of T1 and population density in 1990 has statistically significant impact on neighborhood density change over time. The positive sign of the coefficients show that a higher density in the neighborhoods before the rail transit is built promotes the densification effects of the new line. Meanwhile, the neighborhood population density in 1990 also has direct impact on density change over time. It is not surprising to see that the coefficient on population density in 1990 has a negative sign, which means that the higher the initial population density is in the neighborhood, the less likely the area will continue to densify over time—consistent with previous findings. However, combining the direct impact of pre-project population density (-0.06 in the corridor and node models and -0.32 in the neighborhood model) and the indirect impact through the interaction with treatment dummy (0.16, 0.08, and 0.42 in the three models, respectively), we find that the combined effect of the pre-project population density on population densification is positive when the neighborhood is within a half mile from the Orange Line. This suggests that when a neighborhood is within the impact range of the rail transit, dense neighborhoods would actually continue to attract more population. One explanation to this is the agglomeration effect—neighborhoods with a considerable density before the rail project was constructed have an image of compactness that may attract more compact development of the same fashion.

Table 5: Regression results on population density change, the Chicago case

	A: Corridor Model			B: Node Model			C: Neighborhood Model		
	Coefficient	Beta	Sig.	Coefficient	Beta	Sig.	Coefficient	Beta	Sig.
Treatment dummies									
Within a half mile from rail (T1)	14888.15	1.00	*	22726.47	1.50	*	10416.66	0.60	*
Within a quarter mile from rail	-603.28	-0.02		-872.69	-0.03		-603.28	-0.01	
Station features									
Total parking spots	-7.49	-0.13		-1.06	-0.02		-7.49	-0.10	
Transit accessibility to jobs	0.00	-0.02		-0.01	-0.13		0.00	-0.01	
Neighborhood factors									
Distance in miles from Downtown	1177.55	0.32	***	2044.69	0.58		198.23	0.06	
Within the city boundary of Chicago	9890.77	0.14	*	9324.30	0.17	***			
Neighborhood population Density in 1990	-0.06	-0.11		-0.06	-0.11	***	-0.32	-0.44	***
Percentage of African-Americans in 1990	-4906.59	-0.18	**	-7412.78	-0.24	***	-4279.00	-0.16	***
Poverty rate in 1990	-482.78	-0.01		-9816.94	-0.19	***	-16199.69	-0.30	***
Average household income in 1990	0.32	0.36		0.41	0.52		-0.09	-0.09	
Total single family housing units in 1990	-5.81	-0.06	*	-29.84	-0.33		-6.41	-0.09	
Interaction terms									
T1X distance from downtown	-53.54	-0.02		-1110.30	-0.47		-925.79	-0.33	
T1X population density in 1990	0.16	0.19	**	0.08	0.09	***	0.42	0.43	***
T1X percentage of African-Americans in 1990	-3156.04	-0.02		-1433.44	-0.00		-3783.63	-0.02	
T1X poverty rate in 1990	-7258.05	-0.09		-15189.45	-0.16		-8458.86	-0.08	
T1X Average household income in 1990	-0.39	-0.82		-0.52	-1.09		-0.03	-0.06	
T1X single family housing units in 1990	2.08	0.02		29.49	0.35		2.68	0.02	
R-squared	**0.335**			**0.361**			**0.378**		
Adjusted R-squared	**0.264**			**0.242**			**0.347**		
Number of observations	**176**			**108**			**341**		

***Significant at the 0.001 level; **significant at the 0.05 level; * significant at the 0.1 level.

Also, it is worth noting that the coefficients on the treatment variables of the neighborhood model did not differ a lot from the corridor or the node models, which means that choosing different control groups did not affect the measures of the treatment effects to a large extent. All three models explain about a third of the total variation in the dependent variable, with an R-square value from 0.33 to 0.38, which is pretty good considering the parsimony of the models.

The regression models on housing density change in the Chicago region are presented in Table 6. There are some similarities between the regression results on housing densification and that on population densification. On one hand, the treatment dummies are again not statistically significant in any of the models. On the other hand, the interaction term between the treatment dummy and the pre-transit density in the neighborhood is consistently significant across all three models, suggesting that the pre-transit density is a strong factor that influences the land use impacts of the Orange Line in this case.

Table 6: Regression results on housing density change, the Chicago region

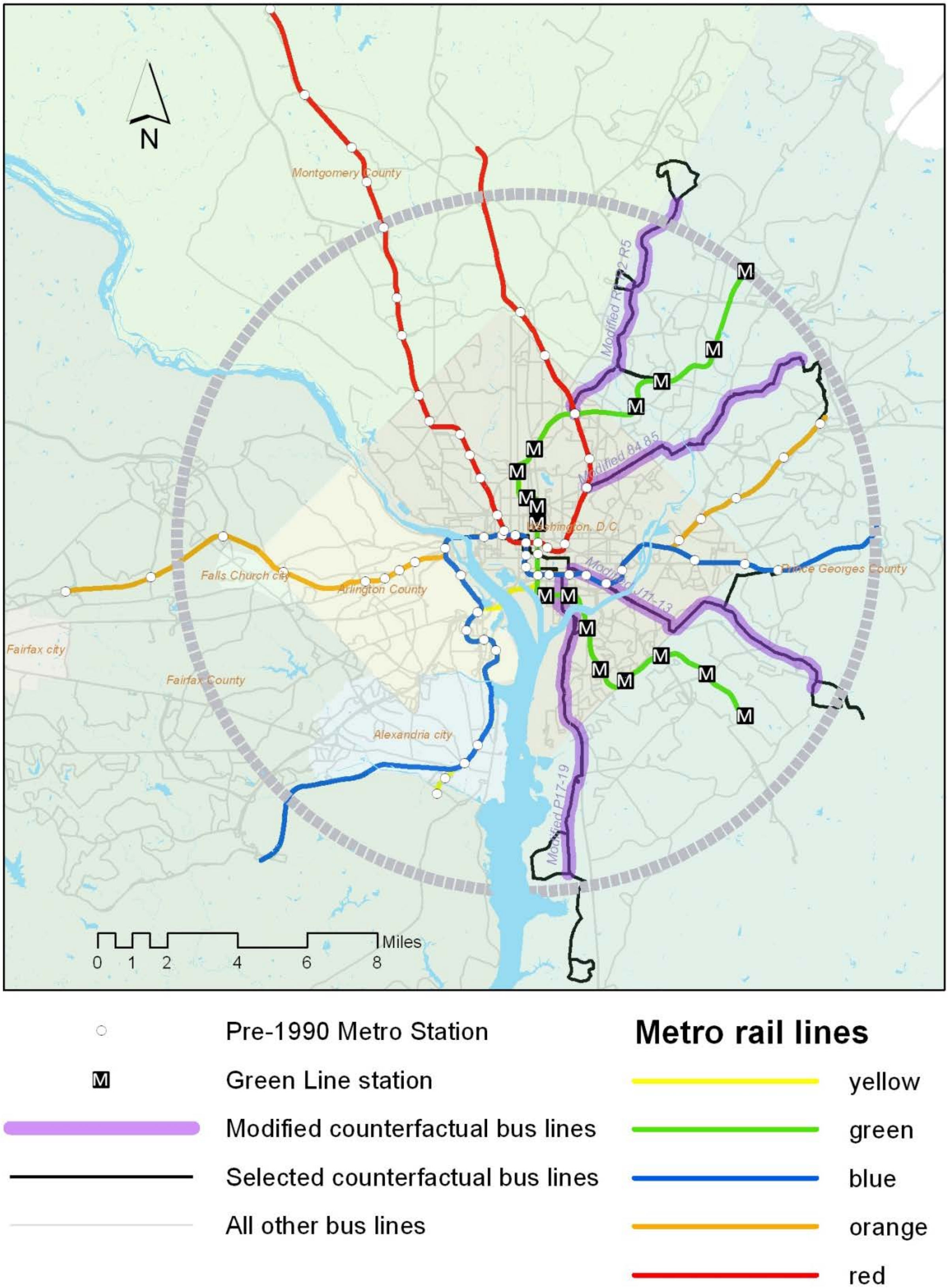
	A: Corridor Model			B: Node Model			C: Neighborhood Model		
	Coefficient	Beta	Sig.	Coefficient	Beta	Sig.	Coefficient	Beta	Sig.
Treatment dummies									
Within a half mile from rail (T1)	4749.05	1.07		3246.94	0.64		-376.32	-0.09	
Within a quarter mile from rail	114.31	0.01		97.19	0.01		114.31	0.01	
Station features									
Total parking spots	-0.91	-0.05		-0.59	-0.03		-0.91	-0.05	
Transit accessibility to jobs	0.00	-0.02		0.01	0.20		0.00	-0.02	
Neighborhood factors									
Distance in miles from Downtown	222.64	0.20	**	455.03	0.39		3.40	0.00	
Within the city boundary of Chicago	2272.06	0.11		1981.06	0.11	***			
Neighborhood housing density in 1990	-0.16	-0.62	***	-0.16	-0.67	***	-0.13	-0.23	***
Percentage of African-Americans in 1990	-549.81	-0.07		-872.78	-0.09	*	-1161.92	-0.18	***
Poverty rate in 1990	-663.80	0.04		-1997.80	0.12		-2371.26	-0.18	*
Average household income in 1990	0.03	0.13		0.05	0.20		-0.02	-0.07	
Total single family housing units in 1990	-2.24	-0.08	*	-10.04	-0.33		-2.12	-0.12	
Interaction terms									
T1X distance from downtown	-268.46	-0.38		-304.86	-0.39		-49.23	-0.07	
T1X housing density in 1990	0.18	0.19	*	0.20	0.27	*	0.17	0.28	**
T1X percentage of African-Americans in 1990	-5128.03	-0.12		-84.98	-0.00		-4515.92	-0.10	
T1X poverty rate in 1990	-911.79	-0.04		-321.49	0.01		-2123.27	0.08	
T1X Average household income in 1990	-0.06	-0.41		-0.04	-0.23	***	-0.01	-0.05	
T1X single family housing units in 1990	0.84	0.03		7.47	0.27		0.72	0.03	
R-squared	**0.434**			**0.535**			**0.140**		
Adjusted R-squared	**0.373**			**0.448**			**0.098**		
Number of observations	**176**			**108**			**341**		

***Significant at the 0.001 level; **significant at the 0.05 level; * significant at the 0.1 level

6.2 Washington, D.C.

1) Sample selection

Following the procedures described in Chapter 3, four bus lines are selected as the counterfactual bus lines for the Green Line in the Washington, D.C. region, which are P17/18/19, J11/12/13, 84/85, and R1/2/5. In addition, the parts of those bus lines outside ten miles from the city center of Washington, D.C. are trimmed off. The rationale of doing this is that a ten-mile radius from city center defines a service region that is similar to where the most remote station on the Green Line is located. After the counterfactual bus lines are selected for the corridor model, counterfactual bus stops for the node model are chosen following the rules described in Chapter 3. Map 24 shows the locations of these counterfactual bus lines and stops in the corridor and node models.



Map 24: The Green Line and the counterfactual bus line/stops in Washington, D.C.

2) Mean comparison

To have an overview of the comparison between the density trends in the two groups of the selected samples, we compared the sample means of population and housing density changes in the control and treatment groups, respectively (Figure 8).

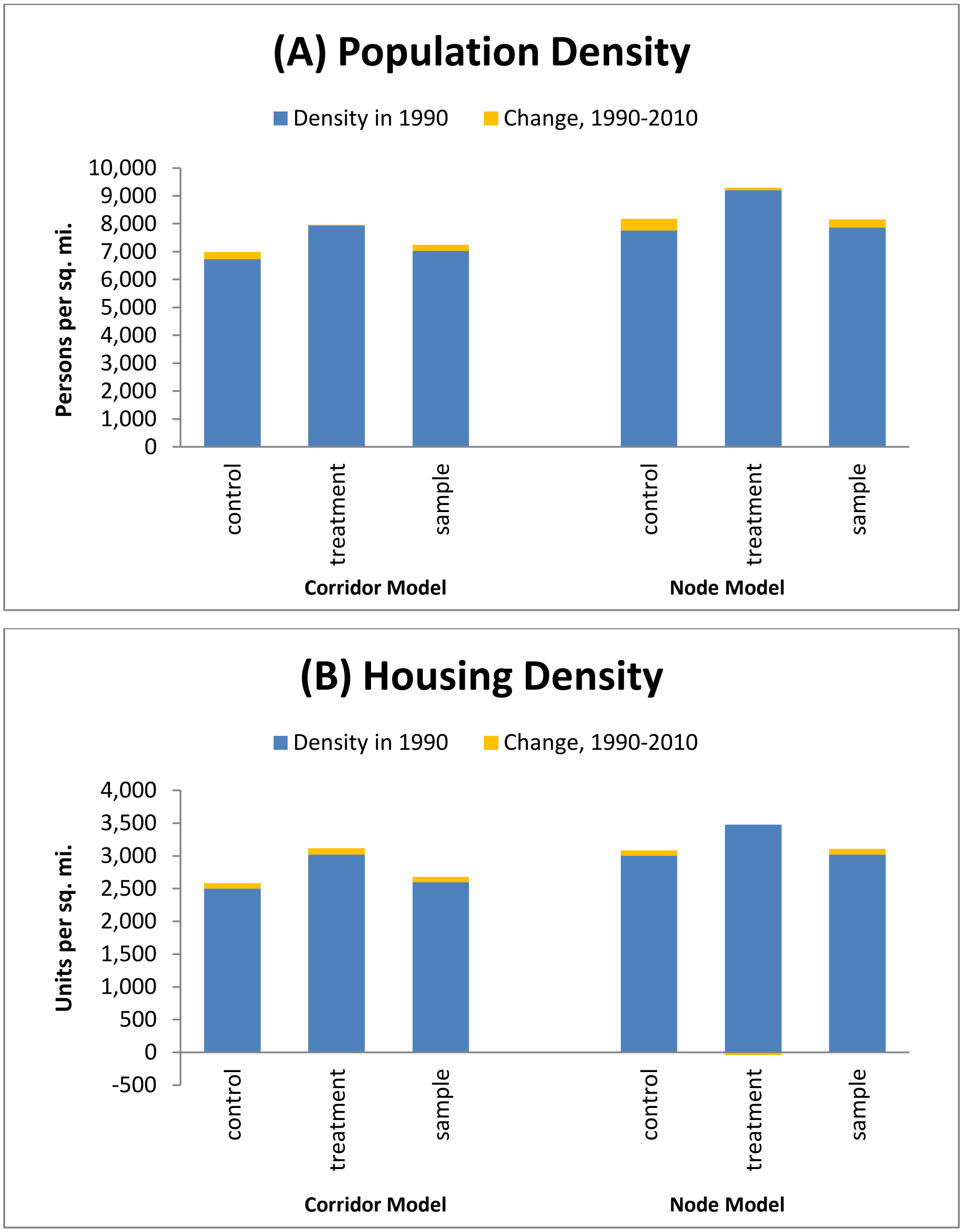


Figure 8: Comparison of the density trend in control and treatment groups of the two models for the case of the Washington Green Line

The results of simple mean comparison show no significant difference between the two groups. The population density even increased slightly more in the control groups than in the treatment groups. However, due to the absence of other controlling factors, such results do not necessarily mean that the Green Line has no densification effect on population or housing in the nearby neighborhoods. We need to proceed to use the proposed DID method and multivariate regression models to control for other factors and separate the impacts of the Green Line from other variables. The key is to compare the current densification results with the “what-if” scenarios—if the Green Line were not built here, would the density of the area be even lower than it is now?

3) Regression results

We started from the same set of candidate variables as the one used in the analysis of the Chicago case. The descriptive statistics of these variables for the selected sample of the Washington, D.C. case are listed in Table 7 on the next page.

It is noteworthy that the average population density change and the average housing density change of the neighborhoods in the selected sample are both negative, which suggests a declining trend in these districts. In this case, even if the Green Line has induced densification effects in the surrounding neighborhood, it is very likely that the density in those neighborhoods still declined between 1990 and 2010. Again, the key is to compare the current densification results with the “what-if” scenarios—if the Green Line were not built here, would the density of the area be even lower than it is now?

Table 7: The descriptive statistics of the variables in the regression models, the Washington case

Variable	Unit	Valid cases	Range	Minimum	Maximum	Mean	Std. Deviation
Dependent variables							
Change in population density, 1990-2010	persons per square miles	290	31728.72	-17814.30	13914.42	-405.91	3782.88
Change in housing density, 1990-2010	units per square miles	290	17872.73	-8001.32	9871.42	-52.28	1502.98
Station features							
Distance from downtown	miles	291	9.95	1.66	11.61	6.08	2.18
Fare to downtown by rail transit	2010 Dollars	120	2.35	1.95	4.30	3.02	0.61
Total parking spots	spots	120	3858.00	0.00	3858.00	1221.78	1134.79
Age of the station as of 2010	years	120	17.00	0.00	17.00	4.87	6.41
Accessibility to jobs by transit		281	83233.58	0	83233.58	3130.48	8651.75
Pre-project neighborhood conditions in 1990							
Population density	persons per square miles	290	35231.03	234.68	35465.71	8788.81	6587.46
Housing density	units per square miles	291	18421.56	0.00	18421.56	3671.88	3192.01
Total population	persons	291	8646.00	70.00	8716.00	1520.32	1204.24
Total number of housing units	units	291	2986.00	0.00	2986.00	628.14	545.58
Percentage of African-Americans		291	1.00	0.00	1.00	0.45	0.38
Percentage of non-citizens		291	0.71	0.00	0.71	0.10	0.12
Unemployment rate		291	0.59	0.00	0.59	0.06	0.07
Poverty rate		291	1.00	0.00	1.00	0.10	0.12
Average household income	1989 Dollars	290	204609.00	2106.00	206715.00	53211.48	31472.23
Number of detached single family housing units	units	291	1073.00	0.00	1073.00	216.14	198.44
Median value for specified owner-occupied housing units	1989 Dollars	277	453901.00	46100.00	500001.00	169115.55	103830.54
Average gross rent for specified renter-occupied housing units	1989 Dollars	279	1368.00	182.00	1550.00	740.83	297.86
Housing vacancy rate		290	0.40	0.00	0.40	0.05	0.06

Table 8 summarizes the results of the regression models on population density change, including both the corridor model and the node model. Overall, the treatment of being within a half mile from the Green Line has a statistically significant and direct effect on increasing population density of the neighborhoods. Moreover, the direct effects of the treatment dummies on the population density increase are more prominent—both in terms of magnitude and statistical significance—in the node models than in the corridor models. This suggests that the access to stations plays a more important role than the proximity to the rail line in the densification of population in the nearby neighborhoods. Being even closer to the Green Line (e.g. within ¼ mile) seems to hinder population densification but the coefficient is not statistically significant.

The treatment dummy variable also has indirect impacts on population densification through its interaction with the following neighborhood factors: distance from downtown (-, significant in corridor model only), pre-project population density (+, significant in corridor model only), share of African-Americans (-), poverty rate (-, significant in node model only), and average household income (-, significant in node model only). Downtown stations have more premier locations than those stations farther away, which amplifies the increased accessibility and attractiveness of the station-area neighborhoods among potential population, thus bringing more population densification. If a neighborhood has already been built quite densely, there is not much room for further densification—a result consistent with what is found in the Chicago case. However, it is worth mentioning that neighborhoods closer to downtown usually have quite high population density before development of the rail line—leaving less potential for more densification. Therefore, the location advantage in promoting densification effect would only be realized when there is room for more densification.

Table 8: Regression results on population density change, the Washington, D.C. region

Independent Variables	Dependent variable: population density change , 1990-2010 (persons per square miles)					
	(1) Corridor model			(2) Node model		
	Coefficient	Standardized Coefficient	Sig.	Coefficient	Standardized Coefficient	Sig.
Treatment dummies						
Within 1/2 mile from rail (T1)	13053.87	1.31	**	36177.46	3.23	***
Within 1/4 mile from rail	-2511.61	-0.11		-2561.58	-0.13	
Station features						
T1 X Total parking spots at station	1.81	0.32	**	2.41	0.36	**
T1 X Accessibility to jobs by transit	-0.03	-0.06		-0.11	-0.26	
Neighborhood factors						
Distance from the station	-619.33	-0.14	*	-593.96	-0.12	
Distance from downtown	0.51	0.00		-77.15	-0.04	
Within the boundary of DC	-1620.12	-0.20	**	-2166.79	-0.24	**
Population density in 1990	-0.45	-0.79	***	-0.48	-0.78	***
Total population in 1990	0.98	0.32	***	1.09	0.33	***
% African-American population in 1990	-481.89	-0.05		-565.05	-0.05	
Poverty rate in 1990	5905.05	0.18		5526.75	0.17	
Average household income in 1990	-0.01	-0.05		-0.01	-0.04	
Total single family housing units in 1990	-4.56	-0.24	***	-4.63	-0.21	**
Interaction terms						
T1 X Distance from the station	-1030.48	-0.06		-11773.05	-0.37	
T1 X Distance from downtown	-2146.88	-1.28	***	-3407.27	-1.74	***
T1 X Population density in 1990	0.16	0.23	*	0.01	0.01	
T1 X % African-Americans in 1990	-5598.54	-0.42	**	-11847.46	-0.79	***
T1 X Poverty rate in 1990	-10803.36	-0.33	**	-16815.91	-0.51	**
T1 X Ave. household income in 1990	-0.02	-0.06		-0.14	-0.47	
T1 X Total single family housing units in 1990	2.60	0.07		-1.63	-0.04	
R-squared	**0.440**			**0.526**		
Adjusted R-squared	**0.397**			**0.461**		
Number of observations	**277**			**166**		

***Significant at the 0.001 level; **significant at the 0.05 level; * significant at the 0.1 level.

Having concentrated African-American population or high poverty rate in the neighborhood seems to hinder the densification effects of the rail project as well, which is probably due to the negative image associated with these factors. However, controlling for other socio-economic factors, a neighborhood with higher average household income is less likely to densify in population. One explanation is that high-income neighborhoods are usually less likely to embrace densification.

Other common neighborhood factors in the two models that are relevant to population densification but are not interacted with the treatment dummy include: distance from the closest rail station (-), within the boundary of the central city (-), pre-project population density (-), total population (+) and total number of single family housing units (-). The last one is of particular interest to this study. The total number of single family housing units in the neighborhood is a proxy indicator of the strength of neighborhood opposition to densification, because low-density single family housing owners are more likely to go against dense development than renters or owners of multi-family housing. Another explanation is that the prevalence of single-family housing units in a neighborhood usually means that the area is largely zoned to be low-density residential use, which usually restricts dense development in the area.

The model results on the housing density change showed a quite different story: the treatment dummies are not significant in either the corridor or the node model (Table 9). But the results on the corridor model show that being close to the Green Line may have an indirect impact on densification through its interaction with the pre-project housing density in the neighborhood. Although the direct impact of pre-project housing density is that higher pre-project density leads to less densification, being in the impact range of the Green Line can offset some of that impact.

Table 9: Regression results on housing density change, the Washington, D.C. region

Independent Variables	Dependent variable: housing density change , 1990-2010 (housing units per square miles)					
	(1) Corridor model			(2) Node model		
	Coefficient	Standardized Coefficient	Sig.	Coefficient	Standardizec Coefficient	Sig.
Treatment dummies						
Within 1/2 mile from rail (T1)	-3622.14	-0.99		-3379.23	-0.84	
Within 1/4 mile from rail	-888.26	-0.11		5.78	0.00	
Station features						
T1 X Total parking spots at station	-0.33	-0.16		-0.48	-0.20	
T1 X Accessibility to jobs by transit	0.00	-0.03		-0.02	-0.12	
Neighborhood factors						
Distance from the station	-161.44	-0.10		-178.92	-0.10	
Distance from downtown	-26.42	-0.04		-46.06	-0.07	
Within the boundary of DC	-191.76	-0.06		-317.38	-0.10	
Housing density in 1990	-0.16	-0.77	***	-0.18	-0.81	***
Total population in 1990	0.22	0.20	***	0.25	0.21	**
% African-American population in 1990	218.86	0.06		284.51	0.07	
Poverty rate in 1990	2677.07	0.22	*	4187.38	0.36	**
Average household income in 1990	0.00	-0.01		0.00	0.03	
Total single family housing units in 1990	-1.40	-0.20	***	-1.42	-0.17	*
Interaction terms						
T1 X Distance from the station	-583.63	-0.09		2501.83	0.22	
T1 X Distance from downtown	265.92	0.43		167.07	0.24	
T1 X Housing density in 1990	0.15	0.26	**	0.14	0.23	
T1 X % African-Americans in 1990	-68.32	-0.01		-660.86	-0.12	
T1 X Poverty rate in 1990	637.92	0.05		-238.33	-0.02	
T1 X Ave. household income in 1990	0.04	0.42		0.03	0.27	
T1 X Total single family housing units in 1990	0.88	0.07		1.70	0.12	
R-squared	**0.347**			**0.403**		
Adjusted R-squared	**0.296**			**0.322**		
Number of observations	**277**			**166**		

***Significant at the 0.001 level; **significant at the 0.05 level; * significant at the 0.1 level.

Comparing the results from the two tables (Table 8 and Table 9), the findings suggest that the Green Line imposes both direct and indirect impacts on population densification but only marginal indirect impacts on housing densification. In other words, there seems to be a mismatch between the significance of the densification impacts on population and on housing.

Usually, as the conceptual framework of densification mechanisms (Figure 5) in Chapter 3 describes, population densification in an area will lead to increased housing demand, which will then lead to increased housing supply—namely, housing densification—in the area. However, the planning process, land assembly and the construction of housing development usually takes years. Therefore, one explanation to the mismatch is that there is simply a time lag between population densification and housing densification to follow. If this holds true, housing densification should catch up with population densification in the end and the supply and demand of housing should reach a new equilibrium.

Another explanation, according to the conceptual framework, is that housing densification is not allowed to happen due to certain land use constraints. If that is the case, then the mismatch between population and housing densification suggests that certain land use regulations may have hindered the possible housing development needed to accommodate the increased population in the area.

6.3 Denver

1) Sample selection

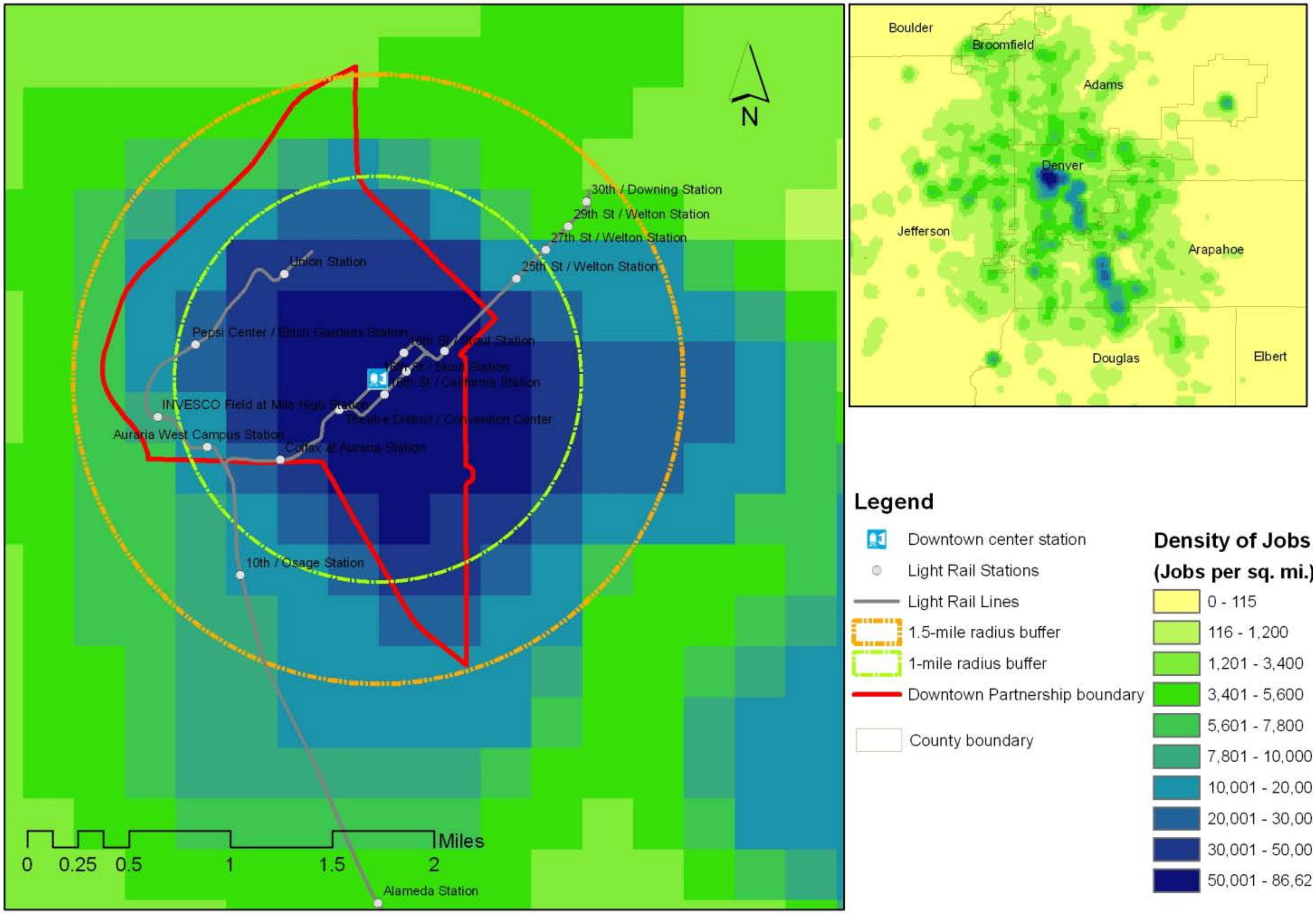
The steps of selecting the sample for using the DID models to evaluate the densification effects of the D Line are very similar to the ones taken in the Chicago or the Washington case, except for one more step—to exclude the downtown area from the analysis. Downtown is such a unique place that its development pattern differs quite a lot from the rest neighborhoods in the metropolitan region; therefore, it would not be reasonable to compare station areas within downtown with other neighborhoods in the region. For the ease of spatial analysis, this study defines the territory of downtown Denver as the area within 1.5 miles from the central rail station—16th & Stout. The selection of the 1.5-mile radius is based on 1) the current boundary of Downtown Partnership[4] and 2) the analysis of the spatial distribution of job density as of Year 2008. Map 25 on the next page shows the kernel density of jobs in the metropolitan region.

---

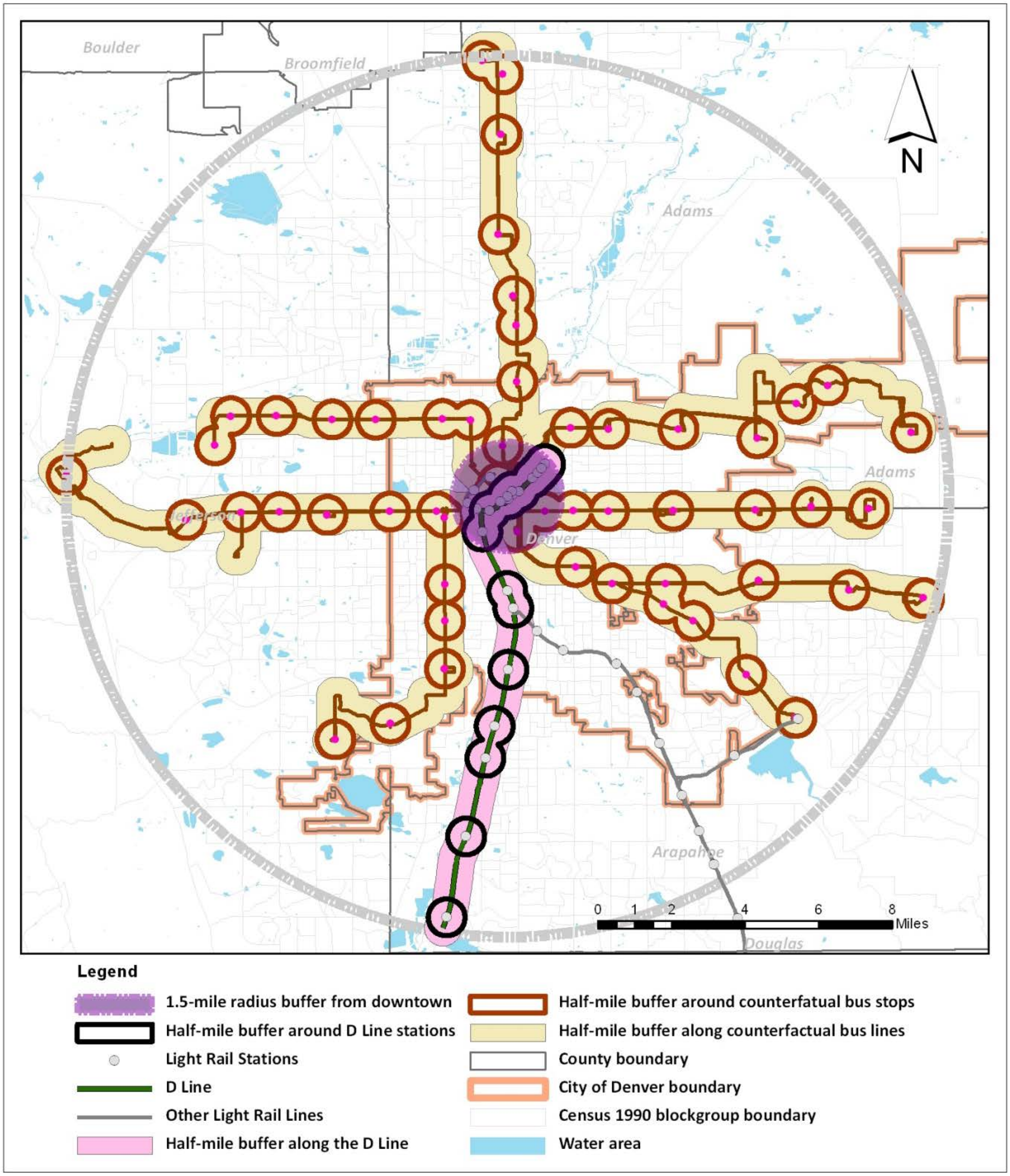
[4] The map of Downtown Partnership boundary is retrieved on November 12, 2012 from the following website: http://www.experiencedowntowndenver.com/splashmap/tdm_splash_map/bin/tdm_splash_map.html

A 1.5-mile buffer zone seems to embrace the part where the highest concentration of employment is located—the working definition of downtown Denver in this study.

After excluding the downtown area, this study selects neighborhoods for a corridor model and a node model to evaluate the densification effects of the D Line in Denver. The construction of the control groups and the selection of counterfactual bus lines and stations were almost identical to that of the Chicago and the Washington case. First, we select bus lines that go in a radial fashion from downtown to the suburbs, similar to the way of rail D Line. Then, among all the bus lines that meet the first criterion, the lines with higher ridership were selected. In addition, we also remove the bus stations farther than ten miles from the center of downtown, a distance that is similar to where the most remote station on the D Line is located. Following the procedure described above, seven bus lines are selected as the counterfactual bus lines, which are 15, 16, 30, 3L, 44, 8, 83L. The neighborhoods within a half mile along these lines make the control group in the corridor model, while the neighborhoods within a half mile along the D line become the treatment group in the same model.



Map 25: The downtown area in Denver to be excluded from sample selection



Map 26: The counterfactual bus lines and stops selected for comparing with the D Line in Denver

For the corridor model, the treatment group is consisted of the neighborhoods within a half mile around the D Line stations, while the control group is consisted of the neighborhoods within a half mile around the counterfactual bus stops on the counterfactual bus lines selected above. Similar to the procedure described in the Chicago and Washington cases, we first pick the major stops on the timetable of each counterfactual bus line as the candidates. Then a four-to-six-minute spacing rule was applied to ensure that the counterfactual bus stops would have similar spacing as the D Line stations do. The finalized counterfactual bus stops used in the node model are shown in Map 26 on the next page, which also shows the counterfactual bus lines used in the corridor model.

2) Mean comparison

After selecting the control groups and the treatment groups in the two types of models, we can compare the population and housing density trend in those groups (Figure 9) to overview the density comparison between the transit-served and non-transit-served neighborhood groups.

The results of simple mean comparison show a clear contrast between the trends in population and housing densification of the control and the treatment groups. Population density seems to increase slightly more in the control groups than in the treatment groups, while housing density seems to increase more in the treatment groups than in the control groups. Whether such difference is statistically significant, and whether such difference is caused by the rail transit, however, can only be revealed in the next section, using the proposed DID method and multivariate regression models to control for other factors.

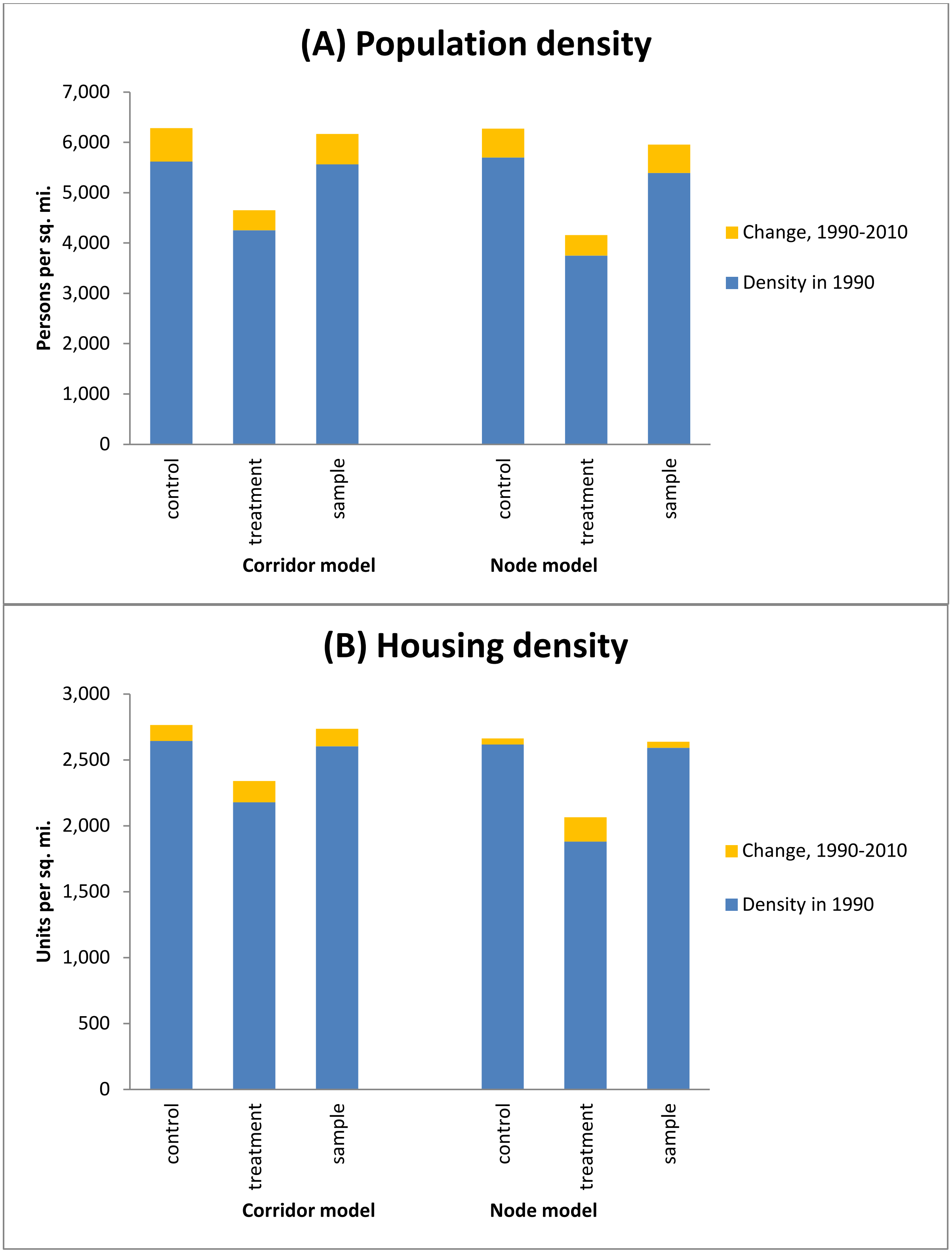


Figure 9: Comparison of the density trend in control and treatment groups of the two models for the case of the Washington Green Line

3) Regression results

Table 10 below presents the descriptive statistics of the variables to test in the models.

Table 10: The descriptive statistics of the variables in the regression models, the Denver case

Variable	Unit	Valid cases	Range	Minimum	Maximum	Mean	Std. Deviation
Dependent variables							
Change in population density, 1990-2010	persons per square miles	452	27394.15	-9287.47	18106.68	883.39	3130.73
Change in housing density, 1990-2010	units per square miles	452	17503.27	-8203.44	9299.83	189.84	1743.97
Station features							
Distance from downtown	miles	452	12.25	0.00	12.25	4.58	2.98
Fare to downtown by rail transit	2010 Dollars	452	1.75	2.25	4.00	2.34	0.38
Total parking spots	spots	452	1248.00	0.00	1248.00	204.48	402.33
Age of the station as of 2010	years	452	6.00	10.00	16.00	15.22	2.02
Accessibility to jobs by transit		452	73829.66	0	73829.66	3461.9118	10997.72
Pre-project neighborhood conditions in 1990							
Population density	persons per square miles	452	32851.05	279.37	33130.42	7149.88	5520.80
Housing density	units per square miles	452	29361.09	0.00	29361.09	4316.87	4915.74
Total population	persons	452	2972.00	48.00	3020.00	872.55	462.17
Total number of housing units	units	452	2465.00	0.00	2465.00	452.20	275.03
Percentage of African-Americans		452	0.96	0.00	0.96	0.12	0.18
Percentage of non-citizens		452	0.37	0.00	0.37	0.04	0.06
Unemployment rate		452	0.56	0.00	0.56	0.08	0.08
Poverty rate		452	0.84	0.00	0.84	0.19	0.17
Average household income	1989 Dollars	451	140644.00	5507.00	146151.00	30817.31	17212.18
Number of detached single family housing units	units	452	644.00	0.00	644.00	175.58	132.95
Median value for specified owner-occupied housing units	1989 Dollars	414	332500.00	31400.00	363900.00	81288.89	42213.69
Average gross rent for specified renter-occupied housing units	1989 Dollars	444	1370.00	103.00	1473.00	438.80	153.35
Housing vacancy rate		451	0.57	0.00	0.57	0.13	0.09

Applying the DID method described in Chapter 3 to the samples selected above, we come up with the regression results on the density change in population (Table 11) and housing (Table 12). Unfortunately, the treatment variables, whether a neighborhood is within a half mile from the D Line (corridor models) or the stations on the D Line (node models), appear to have negative coefficients in all models, although they are not no statistical significant. This suggests that the proximity to the D Line has no direct impact on promoting densification in the neighborhoods. The only interaction terms that shows statistical significance in all models is the product of treatment dummy and pre-transit density, which is consistent with the previous cases.

Table 11: Regression results on population density change, the Denver case

Independent variables	Dependent variable: Change in population density, 1990-2010 (persons per square miles)					
	(1) corridor model			(2) node model		
	Coefficient	Standardized Coefficient	Sig.	Coefficient	Standardized Coefficient	Sig.
Treatment variables						
Within a half mile from rail (T1)	-1562.87	-0.18		-9173.64	-1.14	
Within a quarter mile from rail	-775.08	-0.08		-2293.35	-0.27	
Station features						
T1 X Total parking spots	-0.16	-0.01		-0.46	-0.02	
T1 X Years of operation as of 2010	66.97	0.11		478.91	0.88	
T1 X Accessibility to jobs by transit	0.03	0.12		0.05	0.20	
Neighborhood factors						
Distance in miles from downtown	-89.38	-0.08		-140.38	-0.13	
Within the city boundary of Denver	-437.71	-0.07		282.80	0.04	
Neighborhood population density in 1990	-0.10	-0.17	***	-0.13	-0.24	***
Percentage of African-Americans in 1990	3897.87	0.22	***	2290.30	0.14	
Poverty rate in 1990	-2676.05	-0.14	*	-3369.36	-0.18	
Average household income in 1990	-0.03	-0.15	**	-0.02	-0.11	
Single family housing units in 1990	-4.00	-0.17	***	-6.47	-0.25	***
Interaction terms						
T1X distance from downtown	-89.25	-0.05		445.22	0.21	
T1X population density in 1990	-0.35	-0.33	***	-0.31	-0.31	**
T1X Percentage of African-Americans in 1990	-2853.32	-0.10		-1667.21	-0.07	
T1X poverty rate in 1990	1726.02	0.07		3210.33	0.17	
T1X average household income in 1990	0.02	0.07		0.02	0.06	
T1X single family housing units in 1990	7.05	0.14		11.90	0.23	
R-squared	**.140**			**.139**		
Adjusted R-squared	**.104**			**.069**		
Number of observations	**450**			**239**		

***Significant at the 0.001 level; **significant at the 0.05 level; * significant at the 0.1 level.

Table 12: Regression results from the final DID models on the density change in population and housing, the case of the D Line in Denver

Independent variables	Dependent variable: Change in housing density, 1990-2010 (housing units per square miles)					
	(1) corridor model			(2) node model		
	Coefficient	Standardized Coefficient	Sig.	Coefficient	Standardized Coefficient	Sig.
Treatment variables						
Within a half mile from rail (T1)	-2580.45	-0.54		-4962.81	-1.04	
Within a quarter mile from rail	-235.88	-0.04		-935.96	-0.19	
Station features						
T1 X Total parking spots	-0.38	-0.04		-0.51	-0.04	
T1 X Years of operation as of 2010	93.52	0.28		277.52	0.86	
T1 X Accessibility to jobs by transit	0.06	0.39	***	0.06	0.43	**
Neighborhood factors						
Distance in miles from downtown	-95.11	-0.16	**	-145.73	-0.23	*
Within the city boundary of Denver	90.89	0.03		0.52	0.00	
Housing density in 1990	-0.13	-0.37	***	-0.14	-0.40	***
Percentage of African-Americans in 1990	394.90	0.04		213.53	0.02	
Poverty rate in 1990	-2092.31	-0.20	***	-1833.66	-0.17	
Average household income in 1990	-0.01	-0.07		0.00	0.03	
Single family housing units in 1990	-2.57	-0.20	***	-4.13	-0.26	***
Interaction terms						
T1X distance from downtown	140.17	0.14		303.21	0.24	
T1X housing density in 1990	-0.36	-0.39	***	-0.35	-0.34	***
T1X Percentage of African-Americans in 1990	-609.50	-0.04		-1086.92	-0.08	
T1X poverty rate in 1990	1227.24	0.10		1415.34	0.12	
T1X average household income in 1990	0.00	-0.01		-0.02	-0.08	
T1X single family housing units in 1990	4.44	0.16		6.83	0.22	
R-squared	**.209**			**.204**		
Adjusted R-squared	**.176**			**.139**		
Number of observations	**450**			**239**		

***Significant at the 0.001 level; **significant at the 0.05 level; * significant at the 0.1 level.

For both population and housing densification, high pre-project density and high poverty rate both tend to mitigate the densification in the neighborhood, which is consistent with the findings from the Chicago and Washington.

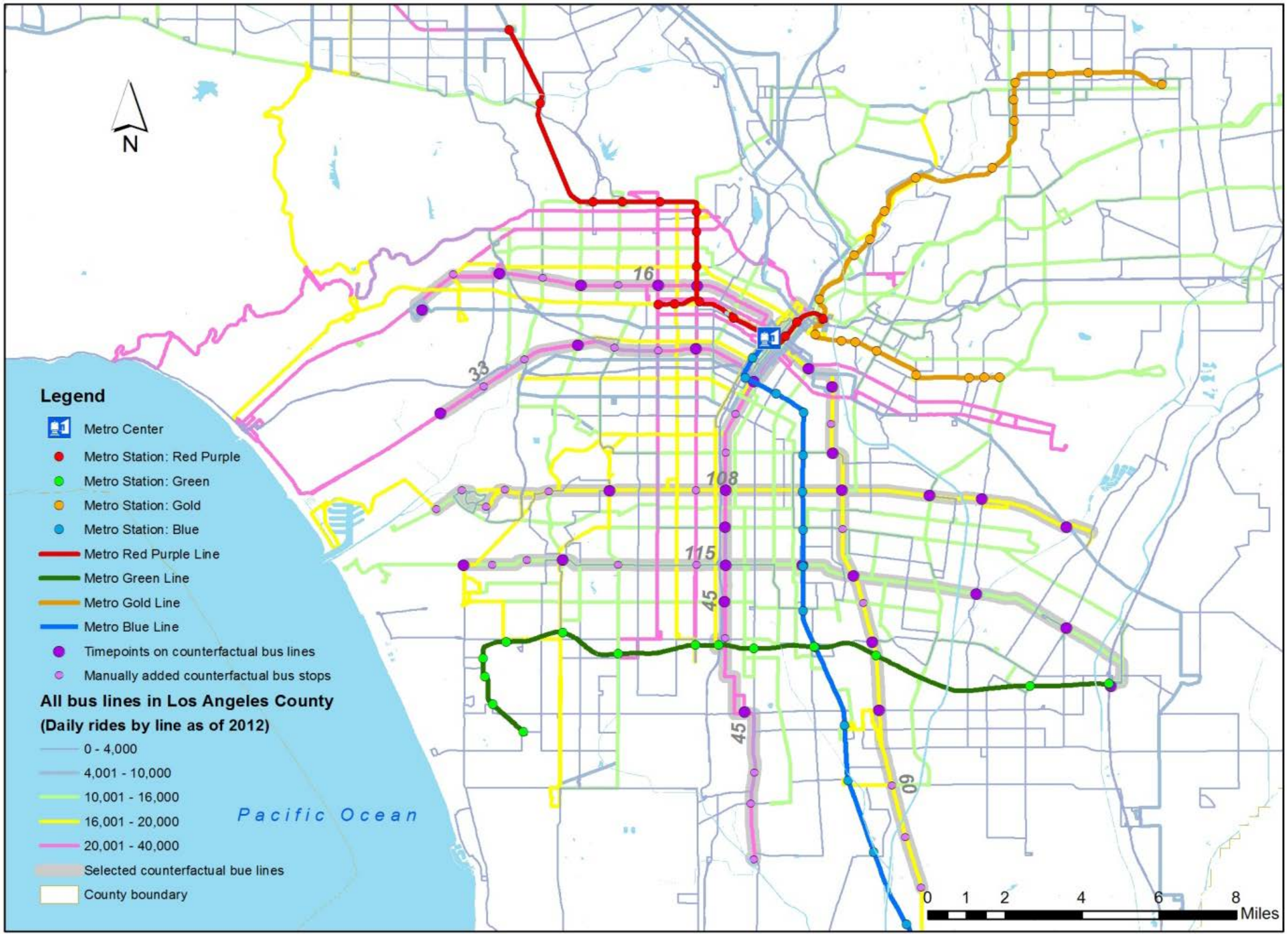
Another finding consistent with that from the Washington case is that the presence of a large number of detached single-family housing units present in the neighborhood tends to hinder housing densification in the area. As explained in the previous case, neighborhood opposition to density and the prevalence of low-density single-family housing zoning are two possible reasons behind this phenomenon.

6.4 Los Angeles

1) Sample selection

The selection process of the treatment neighborhoods and the counterfactual neighborhoods the Los Angeles case is very similar to that of the Denver case.

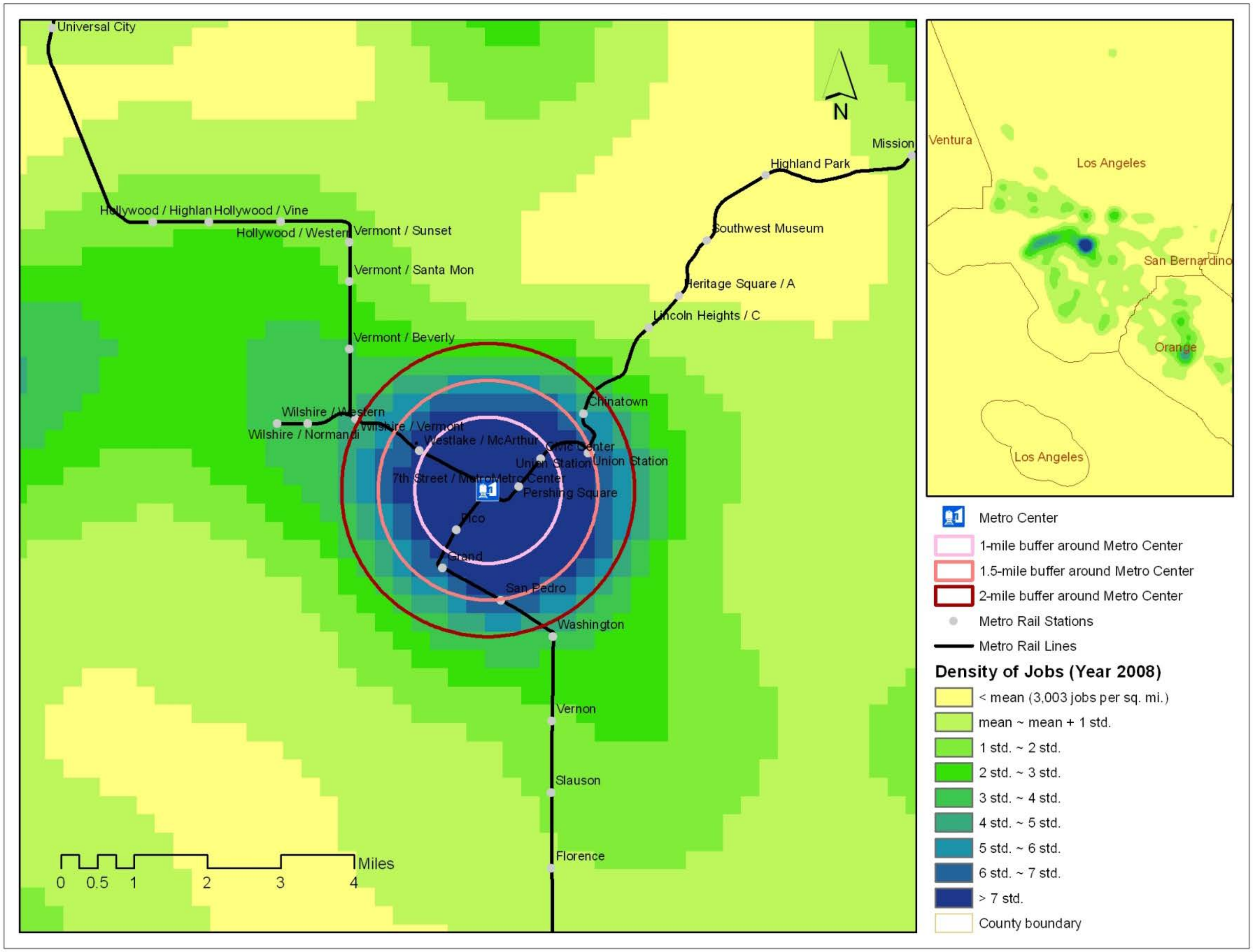
Since there are three rail lines that this study tries to investigate in the Los Angeles case, and each line runs in a different part and direction, we took separate steps to make the selection of counterfactual bus lines for each line. For example, the Red Line runs from downtown Los Angeles to the northwest side of the region, therefore, its counterfactual bus lines should run in the same part. The Blue Line expands from downtown to the south side of the region, its counterfactual bus lines should go in the same direction as well. Among all the bus lines that show similar geographic locations as the rail lines under study, those with higher ridership are selected. Following these criteria, this study chooses six bus lines as counterfactuals to the three rail lines under study in the Los Angeles case (Map 27). Bus lines 16 and 33 are the counterfactuals for the Red Line. Bus lines 45 and 60 are the counterfactuals for the Blue Line. Bus lines 108 and 115 are the counterfactuals for the Green Line.



Map 27: The counterfactual bus lines and stops in the Los Angeles case region

In the station models, the control group only contains neighborhoods within a half mile from selected bus stops on those selected counterfactual bus lines in the corridor models described above. The selection of these counterfactual bus stops starts with selecting the time points on the schedule table of each counterfactual bus line. Then additional stops are manually added when the distance between two time points on the counterfactual bus line is much farther than the station spacing on the parallel rail line under study. This is to ensure that these counterfactual bus stops would have similar spacing as the rail line stations. The finalized counterfactual bus stops are shown in Map 27 above.

One last step in the sample selection for the Los Angeles case is to exclude the downtown area from the analysis, just as what has been done in the Denver case. The rationale, as stated before, is to avoid the "apple-to-orange" comparison between downtown neighborhoods and other neighborhoods in the metropolitan region. Using the same technique applied in the Denver case, this study collects employment data from Year 2008 and calculates the kernel density of jobs in metropolitan Los Angeles (Map 28). The results show that the jobs are concentrated within the 2-mile radius area around the Metro Center rail station. That area becomes the zone defines downtown Los Angeles in this study.



Map 28: The downtown area to be excluded from analysis in the Los Angeles case

2) Mean comparison

As in all other three cases, after selecting the control groups and the treatment groups in the two types of models, we first compare the population and housing density trend in those groups (Figure 10) to overview the density comparison between the transit-served and non-transit-served neighborhood groups.

Before the transit lines were introduced, the average density in the treatment neighborhoods is higher than the average density in the control neighborhoods in 1990, both in terms of population and housing densities. The changes in population density in the two groups over the twenty years after 1990 seem to be almost the same. The change in housing density in the treatment neighborhoods, however, is more than double of the housing density change in the control neighborhoods. These findings show a potential of densification effects of the rail lines on housing rather than population in the Los Angeles region. We will continue with multivariate regression analysis to control for other factors and reveal the causality between the rail lined under study and the densification trend in these neighborhoods.

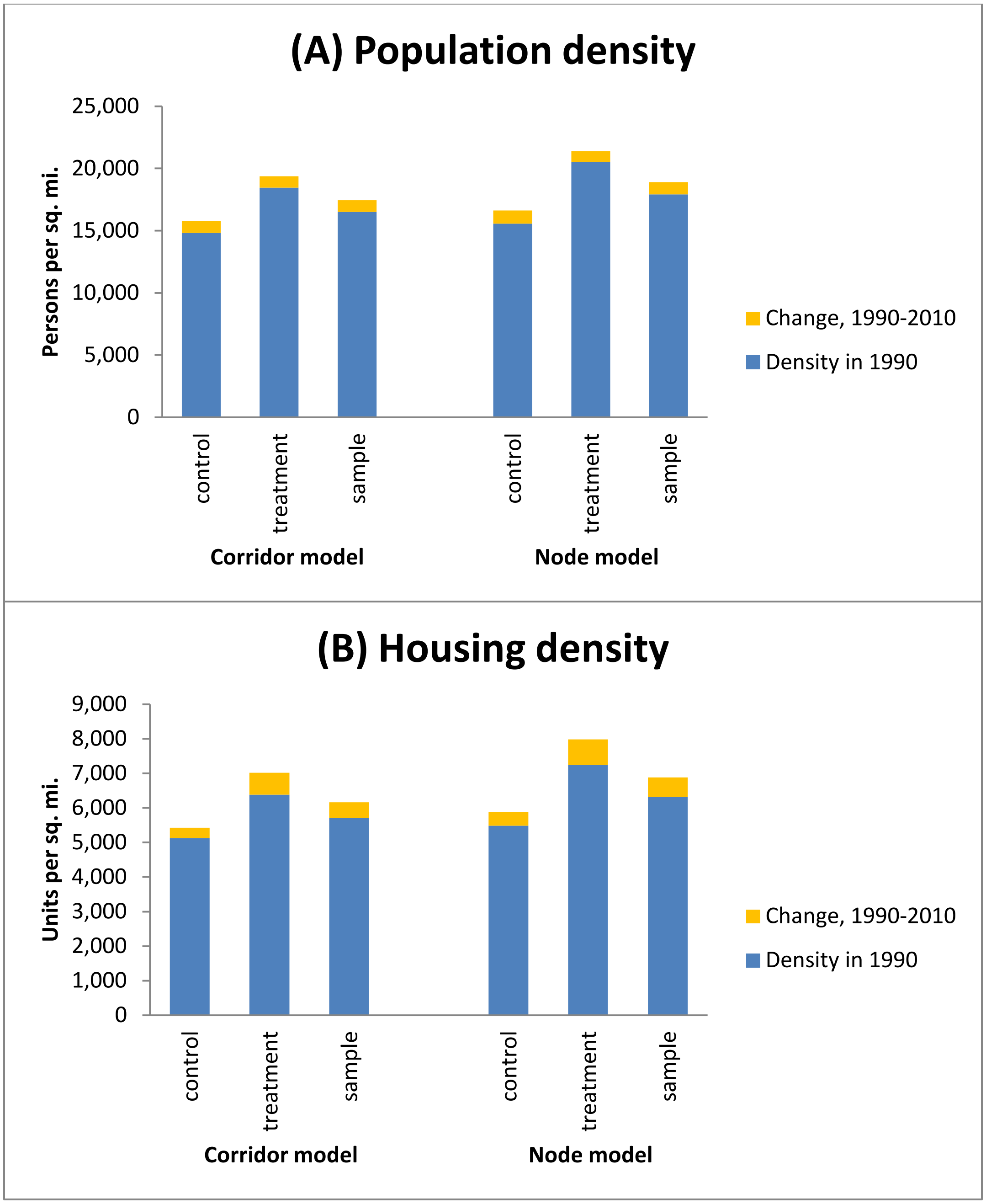


Figure 10: Comparison of the density trend in control and treatment groups of the two models for the case of the Los Angeles region

3) Regression analysis

Following the same routine as in the other cases, we start with the same set of the four categories of variables to be included in the regression analysis. The descriptive statistics of these variables are listed in the table below.

Table 13: The descriptive statistics of the variables in the regressions, the Los Angeles case

Variable	Unit	Valid cases	Range	Minimum	Maximum	Mean	Std. Deviation
Dependent variables							
Change in population density, 1990-2010	persons per square miles	812	43469.67	-14742.71	28726.96	936.08	4987.37
Change in housing density, 1990-2010	units per square miles	812	18594.62	-6027.04	12567.59	453.49	1487.83
Station features							
Distance from downtown	miles	812	15.39	1.01	16.40	6.89	3.03
Fare to downtown by rail transit	2010 Dollars	812	1.50	1.50	3.00	2.01	0.71
Total parking spots	spots	812	1502.00	0.00	1502.00	220.69	320.18
Age of the station as of 2010	years	812	10.00	8.00	18.00	13.90	3.35
Accessibility to jobs by transit		812	94840.93	7788.40	102629.33	31739.46	14437.96
Pre-project neighborhood conditions in 1990							
Population density	persons per square miles	812	90359.52	29.04	90388.56	16499.28	11981.72
Housing density	units per square miles	812	35351.50	9.37	35360.87	5705.01	5015.43
Total population	persons	812	8336.00	43.00	8379.00	1443.55	968.23
Total housing units	units	812	3163.00	16.00	3179.00	501.26	406.57
Percentage of African-Americans		812	0.98	0.00	0.98	0.28	0.29
Percentage of non-citizens		812	0.85	0.00	0.85	0.28	0.19
Unemployment rate		812	0.69	0.00	0.69	0.11	0.08
Poverty rate		812	1.00	0.00	1.00	0.23	0.15
Average household income	1989 Dollars	812	345187.00	4000.00	349187.00	35959.93	28517.64
Number of detached single family housing units	units	812	1020.00	0.00	1020.00	161.89	116.31
Median value for specified owner-occupied housing units	1989 Dollars	754	467501.00	32500.00	500001.00	191548.05	112444.66
Average gross rent for specified renter-occupied housing units	1989 Dollars	803	1292.00	137.00	1429.00	614.45	183.13
Housing vacancy rate		812	0.27	0.00	0.27	0.05	0.04

We also apply the model construction and finalization steps proposed in Chapter 3 to select the best-fitted models. The regression results on the population density change are reported in Table 14, and the regression results on the housing density change are reported in Table 15.

Table 14: Regression results on population density change, the Los Angeles region

Independent Variables	Dependent variable: population density change , 1990-2010 (persons per square miles)					
	(1) Corridor model			(2) Node model		
	Coefficient	Standardized Coefficient	Sig.	Coefficient	Standardizec Coefficient	Sig.
Treatment dummies						
Within 1/2 mile from rail (T1)	-422.78	-0.04		1964.47	0.18	
Within 1/4 mile from rail	-493.23	-0.03		-379.16	-0.02	
Station features						
T1 X Total parking spots at station	2.73	0.14	***	2.76	0.12	*
T1 X Station age	472.37	0.69	***	506.61	0.68	**
T1 X Accessibility to jobs by transit	-0.01	-0.02		-0.01	-0.06	
T1 X Heavy rail	2498.52	0.18	*	2481.48	0.18	
Neighborhood factors						
Distance to downtown	326.13	0.20	**	317.68	0.19	*
Within LA city boundary	1155.65	0.12	**	1302.29	0.12	*
Neighborhood population density in 1990	-0.01	-0.01		0.03	0.07	
Percentage of African-Americans in 1990	-300.11	-0.02		84.55	0.00	
Poverty rate of 1990	1907.18	0.06		2282.38	0.07	
Average Household Income in 1990	0.00	-0.02		0.00	0.00	
Number of single family housing units in 1990	-1.28	-0.03		-2.48	-0.05	
Interaction terms						
T1 X Distance to downtown	-401.49	-0.35	**	-463.93	-0.34	**
T1 X Neighborhood population density in 1990	-0.06	-0.16		-0.08	-0.23	
T1 X Percentage of African-Americans in 1990	1576.15	0.06		3402.84	0.12	
T1 X Poverty rate of 1990	-9113.60	-0.31	***	-13465.25	-0.45	***
T1 X Average Household Income in 1990	-0.05	-0.20	*	-0.08	-0.24	*
T1 X Single family housing units in 1990	-0.31	-0.01		-3.81	-0.06	
R-squared	**0.050**			**0.068**		
Adjusted R-squared	**0.028**			**0.034**		
Number of observations	**811**			**541**		

***Significant at the 0.001 level; **significant at the 0.05 level; * significant at the 0.1 level.

Table 15: Regression results on housing density change, the Los Angeles region

	Dependent variable: housing density change , 1990-2010 (housing units per square miles)					
	(1) Corridor model			(2) Node model		
Independent Variables	Coefficient	Standardized Coefficient	Sig.	Coefficient	Standardized Coefficient	Sig.
Treatment dummies						
Within 1/2 mile from rail (T1)	-1294.26	-0.43		-1032.28	-0.31	
Within 1/4 mile from rail	202.67	0.04		266.92	0.05	
Station features						
T1 X Total parking spots at station	0.54	0.10	*	0.65	0.09	
T1 X Station age (years of operation as of 2010)	136.37	0.66	***	164.60	0.72	***
T1 X Accessibility to jobs by transit	0.01	0.13		0.01	0.18	
T1 X Heavy rail	1578.56	0.38	***	1698.47	0.40	***
Neighborhood factors						
Distance to downtown	21.18	0.04		25.85	0.05	
Within LA city boundary	270.96	0.09	*	329.70	0.09	
Housing density in 1990	-0.01	-0.05		0.03	0.09	
Percentage of African-Americans in 1990	-110.51	-0.02		-52.31	-0.01	
Poverty rate of 1990	326.86	0.03		195.80	0.02	
Average Household Income in 1990	0.00	-0.01		0.00	0.01	
Number of single family housing units in 1990	-0.98	-0.08		-1.25	-0.08	
Interaction terms						
T1 X Distance to downtown	-11.27	-0.03		-10.75	-0.03	
T1 X Housing density in 1990	-0.02	-0.08	*	-0.07	-0.26	**
T1 X Percentage of African-Americans in 1990	440.85	0.06		419.53	0.05	
T1 X Poverty rate of 1990	-2110.14	-0.24	**	-2861.85	-0.31	**
T1 X Average Household Income in 1990	-0.02	-0.26	***	-0.04	-0.35	***
T1 X Single family housing units in 1990	0.14	0.01		-0.57	-0.03	
R-squared	**0.105**			**0.135**		
Adjusted R-squared	**0.083**			**0.104**		
Number of observations	**811**			**541**		

***Significant at the 0.001 level; **significant at the 0.05 level; * significant at the 0.1 level.

All the four models reported in the above two tables have very low R-squared values, ranging from 0.05 to 0.10, which means that these models can only explain less than ten percent of the variance in the dependent variables: population density change or housing density change. One of the reasons why these R-squared values are much lower than in the case of Chicago or Washington, D.C., even lower than in the Denver case is that the sample size of the Los Angles case is the largest among all four regions. A large sample usually has large variance than a small sample. Therefore, the same set of independent variables could explain less part of the variance in a large sample than in a small sample, thus usually yields a smaller R-squared value.

Nevertheless, the results from Table 14 and Table 15 offer insights with regard to the potential of densification effects of the three rail lines in the Los Angeles region. Since Los Angeles is the only case region that has both heavy rail and light rail implemented in the 1990s, we are able to include a unique dummy variable- “heavy rail” in the models. This variable has a positive coefficient on it in all four models, and the coefficients were statistically significant at the 0.01 level for both the corridor and the node models regarding housing density change. This shows that with other neighborhood factors controlled, heavy rail line is more likely to increase density change in the nearby neighborhoods than light rail line. This finding supports previous speculations in the literature. Because of larger passenger capacity, heavy rail can improve the accessibility of a location more than light rail does, hence leaving a bigger incentive for developers to invest in building more housing units in the area. Another significantly influential station feature is the years of operation of a station. The longer the station exists, the more likely it is to make impacts on increasing the neighborhood density nearby.

As for the interaction terms, Table 14 shows that the factors influencing the population densification effects of the rail transit in Los Angeles include the distance from downtown (-), the poverty rate (-) and the average household income (-). None of these three factors are surprising. First, the farther a station is located away from central city, the less likely it will cause population densification in the surrounding neighborhoods because the accessibility improvement brought by a new rail station is weaker at the urban fringe than in the city center. The latter two are also the factors that interfere with the housing densification effects, as is shown in Table 15. Neighborhoods with a concentration of poverty are probably less attractive to potential residents, so are the neighborhoods with high housing values because the housing affordability may be low. Also, like in the previous cases, the interaction between the treatment dummy and the pre-project neighborhood housing density is associated with increase in housing densification, which means that a dense neighborhood provides a friendly environment for the densification effect of rail transit to happen.

Summary of regression analysis

To measure the size of the densification effects of the lines under study while taking into account other neighborhood factors, this study constructs DID models proposed in Chapter 3 and tests various regressions. We start from a set of independent variables which include treatment dummies, station features, neighborhood factors, and the interaction terms between the treatment dummies and the neighborhood factors. The coefficients on the dummy variables are the estimates of the direct densification impacts of the rail lines under study. The coefficients on the interaction terms shed light on the indirect impacts of the rail lines and how those are intertwined with the exogenous factors.

To answer the research questions of this study, we are particularly interested in the direct and indirect densification impacts of the urban rail facilities in the four case regions. Statistically significant direct densification impacts are only observed in the Washington, D.C. case and marginally significant in the Chicago case, in terms of population densification. Indirect densification impacts are found in all four cases, although the factors that affect the indirect impacts vary from one case to another.

The only case that is able to test the influence of transit types on the densification effects is the Los Angeles case, which has both heavy rail and light rail. The findings on this case show that heavy rail does have a more significant effect in causing density increase than light rail, everything else being equal.

The most influential neighborhood factor that interacted with the densification effect of urban rail is the pre-project density in the neighborhood. A dense neighborhood tends to be more likely to promote the densification effects of rail transit than a low-density neighborhood. However, without the presence of rail transit, a high pre-project density in the neighborhood would lead to less densification over time.

Several other findings on the influences of the neighborhood factors are consistent with the theories and previous studies in the literature. On one hand, neighborhoods with high poverty rates or a large concentration of African-Americans are less likely to experience densification effects. On the other hand, neighborhoods with high household incomes suggest lower housing affordability, thus are also less likely to see densification. Such phenomena is consistent with that of a previous study of the transit system in Los Angeles (Loukaitou-Sideris, 2010). The findings that the size of the single family housing stock seems to hinder the population densification may be explained as a reflection of the "NIMBYism"—neighborhoods with a large single family housing stock with good-quality housing properties are least willing to accept more density. A strong alliance of home owners may form official or unofficial groups that prevents population densification through exclusionary acts (A. C. Nelson, 1992), whose concerns are varied but usually include the negative impacts of density on their property values (Pendall, 1999). In short, densification effects are more likely to be observed in moderate-income neighborhoods with a pre-existing pattern of compact development, not dominated by single-family housing, and without a large concentration of poverty.

Chapter 7: Linking the densification effects with station typology

Up to this point, we have found some mixed results regarding the densification effects of the recent rail transit investments in the four case regions. How could we use these findings to inform future policy decisions on rail transit planning, then? After all, the motivation of studying the densification effects is to evaluate the impacts of existing urban rail transit investments and to inform the future investment decisions. Therefore, it would be especially useful if we can present the findings in a way that it could be easily understandable to the general public and the decision makers. This chapter makes such an attempt by linking the densification outcomes with the types of station areas, or, the station typology. It selects key neighborhood features that are important to the densification effects from individual case regions and categorizes the stations into several types based on these neighborhood features. Finally, it experiments with using radar charts to visualize station typology and the potential densification outcomes.

7.1 Defining station typology

From the analysis above, we find evidence on the densification effects of the rail lines under study. We also find that such densification effects are interacted with several factors of the pre-existing conditions of the neighborhoods. We can now summarize and extract key factors of densification from the regression analysis above to construct a framework of defining station typology and linking it with the possible densification outcomes. Doing so may help predict the potential densification effects in different urban settings, thus informing the site selection of future rail facilities.

The working definition of station typology, in the specific context of this study, refers to categorizing the urban rail stations of interest into several types, based on the features of the stations and the pre-existing conditions of the surrounding neighborhoods. According to the sizes of the standardized coefficients on the variables in the corridor and the node models, this study identifies several factors that play significant roles in densification or interaction with the rail treatment. Here we will use the case of Washington, D.C. to exemplify how it works.

The four pre-treatment neighborhood factors that have statistically significant interactions with treatment effect are: average household income (and its squared term), distance from downtown, poverty rate, and the percentage of African-Americans. Using three of these four neighborhood factors, the ten stations on the Green Line can be plotted in the chart below (Figure 11).

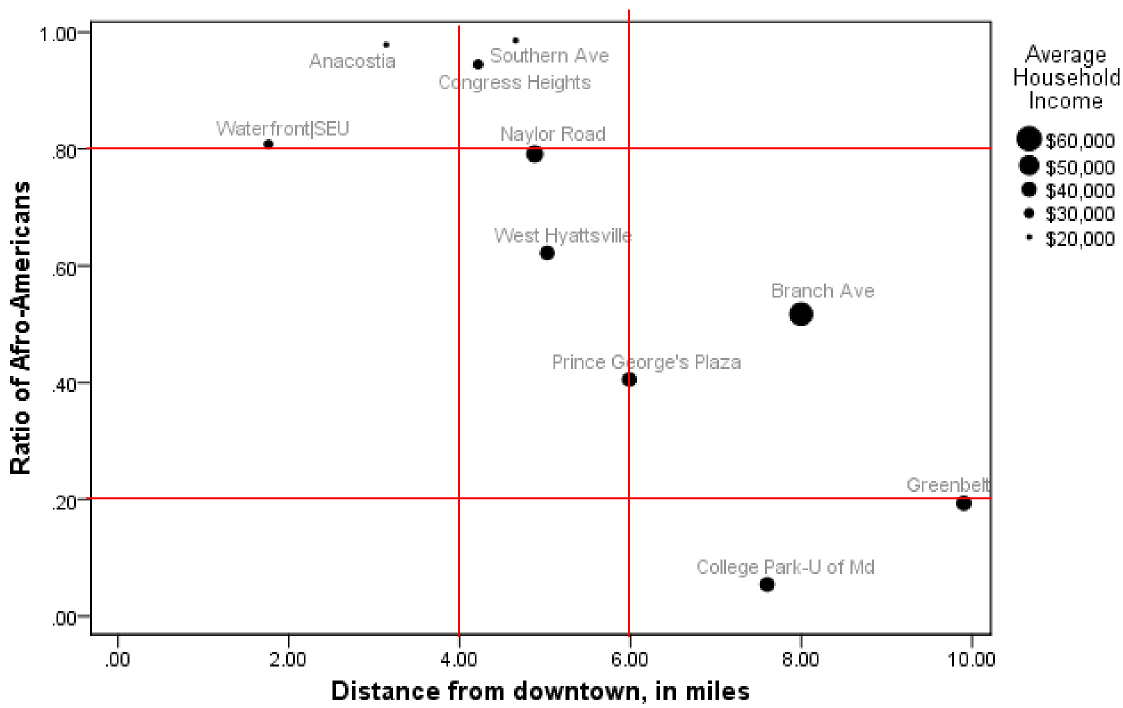


Figure 11: Typology of Green Line stations in metropolitan Washington

Based on the geographic locations of the stations, a station can be either urban (<4 miles from downtown), urban fringe (4-6 miles from downtown), or suburban (>6 miles from downtown)[5]; based on the racial composition of the neighborhoods, a station area can be white-dominant (>80% white), black-dominant (>80% African-Americans), or mixed-race; based

[5] These distance cut-offs used are based on the fact that the central city, i.e. the District of Columbia, sets its boundary at around five miles from city center. Therefore, four to six miles from downtown are considered at the urban fringe. For other metropolitan areas, such cut-offs may vary based on the size of the central city.

on average household income, a station area can be low-income (< $35,000), middle-income ($35,000~$50,000), and high-income(>$50,000)[6]; based on poverty rate, a station area can be very poor (poverty rate>40%[7]), poor (20%<poverty rate<=40%), and not poor (poverty<=20%). Table 17 shows the results of applying such station categorization methods to the Green Line stations in the Washington, D.C. case and lists the densification outcomes in the station areas.

Table 16: The typology of the Washington Green Line stations

Type	Station Name	Typology Dimension				Densification outcomes	
		Geography	*Race*	*Income*	*Poverty*	*Population*	*Housing*
I	Anacostia	Urban	Black	Low	very poor	Negative	Negative
	Waterfront/SEU	Urban	Black	Low	very poor	Negative	Positive
II	Congress Heights	Urban Fringe	Black	Low	poor	Negative	Negative
	Southern Ave	Urban Fringe	Black	Low	poor	Positive	Negative
III	Naylor Road	Urban Fringe	Mixed	Middle	not poor	Negative	Negative
	Prince George's Plaza	Urban Fringe	Mixed	Middle	not poor	Positive	Positive
	West Hyattsville	Urban Fringe	Mixed	Middle	not poor	Positive	Positive
IV	College Park/U of MD	Suburban	White	Middle	very poor	Positive	Negative
V	Branch Ave	Suburban	Mixed	High	not poor	Positive	Positive
VI	Greenbelt	Suburban	White	Middle	not poor	Positive	Positive

Conceptually, following the 3X3X3X3 typology rules described above, a station area can be in any one of the 81 possible combinations of types. According to the regression results, urban, white, middle-income neighborhood without much poverty should be the type that experiences the most positive change in population density. However, such conceptual type does not exist in the case of the Green Line. Instead, the ten Green Line stations fall in only six out of the 81 possible categories, which are summarized below.

(1) Urban black-dominant low-income neighborhood with extreme poverty

[6] These cut-offs are based on the income level of the region at the time. According to Census 1990, the median household income in DC was around $30,727 and $39,386 in Maryland. Therefore, I used the average of $35,000 as the threshold for middle-income neighborhoods.

[7] Using a fixed percentage of the population below poverty line as a criterion to identify poor neighborhoods has been a standard practice in the literature on poverty studies(Coulton, Chow, Wang, & Su, 1996; Quillian, 2003). However, the thresholds used varied from 20%, to 30%, to 40%. Here in this paper, I followed the practice of using 20% as the threshold of defining a poor neighborhood and using 40% as the threshold of defining an extremely poor one.

Two stations, Anacostia and Waterfront/SEU are in this category. And they both experienced negative change in population densification, from before the Green Line was opened to after, though Waterfront station had slight increased housing density. It is not surprising that the advantage of the premier accessibility of an urban location was outweighed by three other factors which shaped a disadvantaged neighborhood socio-economic profile and cast negative impact on the densification effect.

(2) Urban fringe black-dominant low-income neighborhood with some poverty

Congress Heights and Southern Ave stations belong to this category. They both had negative densification in housing, though Southern Ave station had positive change in population densification. Similar to the case of the first type, neighborhoods with both race segregation and low income seem to have some difficulties in realizing the densification effect from rail transit investment.

(3) Urban fringe mixed-race middle-income neighborhood without much poverty

Naylor Road, Prince George's Plaza, and West Hyattsville fall in this category, the latter two of which both had positive density change in population and in housing units (which are not surprising), while the first one had negative change in both. One possible reason for such contrast is that the Naylor Road station is bounded by an elevated highway—Suitland Parkway (Figure 12), which forms a barrier that may have prevented the residents from the north part of the highway to access the Naylor Road station.

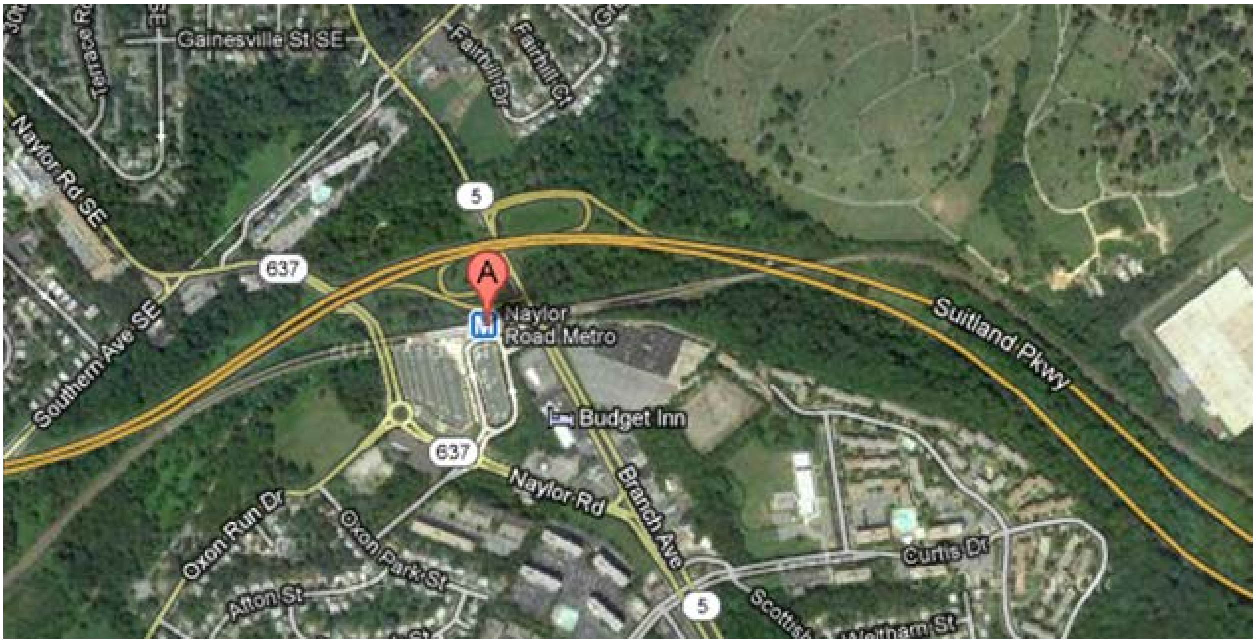


Figure 12: Satellite image of the Naylor Road station area (Courtesy of Google Map)

(4) Suburban white-dominant middle-income neighborhood with extreme poverty

College Park/ U of MD station is the only such kind among all the Green Line stations. It experienced positive change in population density yet negative change in housing density. However, it is worth noting that this station area is where the University of Maryland-College Park campus is. Therefore, the "extreme poverty" label on this area is probably due to the presence of many college students in residence who either have no or very little income. Such unique demographic feature of the population means that such combination of the station typology may only be possible when it comes to university campuses.

(5) Suburban mixed-race high-income neighborhood without much poverty

Branch Ave station belongs to this type, which witnessed both population densification and housing densification from before to after the Green Line project was introduced, a result consistent with the findings and predictions from the regression analysis.

(6) Suburban white-dominant middle-income neighborhood without much poverty

This category is very similar to the last one, and the only station in this category—Greenbelt station also had positive changes in population and housing densities.

7.2 Visualizing station typology and linking it with densification outcomes

Now we have established a system of defining station typology and categorize stations into different types, the next step is to test the connection between these station types, the expected densification outcomes, and the actual densification outcomes.

This research experiences with using a radar chart to visualize station typology (Figure 13 on the next page). Each radar chart represents a station type. It has with four axes, each of which denotes a key factor whose desirability (in terms of promoting densification effect) increases from center to the periphery. For example, on the axis of geography, a suburban location gets a score of 1 and placed in the center, while an urban location gets a score of 3 and placed in the periphery. Similarly, an extremely poor neighborhood also gets a low score of 1 on the axis of poverty and placed in the center. Therefore, station areas with the four factors least favorable to densification would have the smallest covered area on the radar, whereas station areas with four most desirable factors would have the largest covered area on the radar. In this figure, diamonds in red denote those that have negative change in population and housing density; diamonds in blue represent those with positive change in population and housing density.

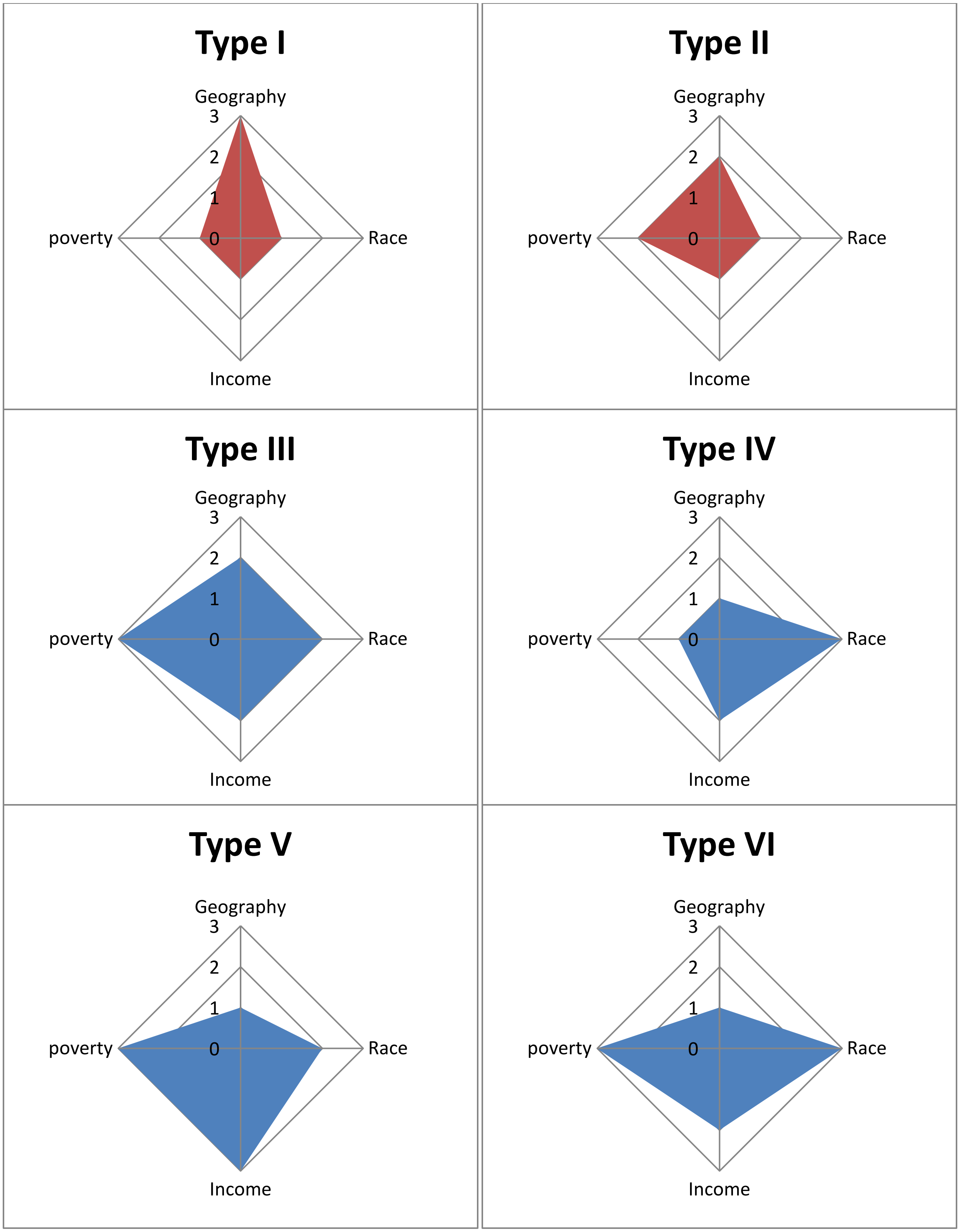


Figure 13: Visualizing station typology in Washington, D.C. using four-axis radar charts

The way we define the coordinates on the four axes suggests an expected relationship between the visualization of station typology and the densification effects: stations with larger covered areas in the diamond charts tend to be more likely to densify. Hypothetically, in the most extreme cases, a station that has the maximum values on all the four axes—which means it has the ideal conditions for promoting densification effects—would have a fully covered diamond. As we can see from the radar charts in Figure 13, the first two types of stations which had mostly negative change in population and housing density (with covered areas in red) also have smallest covered area on their radar charts. More specifically, their covered areas are both smaller than half of the entire diamond area. By contrast, the other four categories that mostly experienced positive densification effect (with blue covered areas) all have fairly large covered areas. In summary, if we may use such visualization to help predict the densification effect on a station area-neighborhood, neighborhoods that have more than half of the diamond area covered are more likely to witness positive density change. Whether this could be a general rule, however, are subject to more evidence from other rail systems.

Summary of the attempt to link densification effects with station typology

On top of the regression analysis that reveals the densification effects of urban rail transit and how neighborhood factors may interfere with those densification effects, this study continues to explore the ways to predict future densification effects using the findings from regression analysis.

In this chapter, we attempt to categorize stations into several types using the most influential neighborhood factors found in the regression analysis and use radar charts to visualize the station typology. The example of the Washington case shows that radar charts work well to present station typology visually. Moreover, the coordinates on the four axes of such radar charts are designed to represent the desirability of the neighborhood condition. Therefore, it is possible to predict the likelihood of potential densification effect by looking at the sizes of the covered area on those radar charts. Station areas with at least two desirable factors (or covered more than half of the diamond area on the radar chart) are more likely to experience densification effect over time. Whether this could be a general rule, however, are subject to more evidence from other rail systems. This technique of data visualization could be useful in community hearings where transit planners can present to the audience the complex relationship between multiple exogenous factors and potential densification outcomes of a proposed new rail transit service in the neighborhood.

Chapter 8: Conclusion

The resurgence of urban rail transit investments in North America since the late 1970s has stimulated a heated debate on the costs and benefits of such large projects. Many supporters believe that rail transit is a worthwhile investment due to its potential in making land use impacts and guiding urban development into a more compact and sustainable way. The classic location theory supports the hypothesis that introducing a new rail transit station should increase the land values and the development densities in the neighborhoods near the stations, because the availability of the rail transit service improves the accessibility and the location advantage of the areas near the station. However, the empirical evidence shows mixed findings on the development effects of modern urban rail transit systems. In some cities, urban rail transit seems to have cause increases in densities, while in others such effects are absent. Even in the same city, the densification effects could vary from one station area to another. Such a big variance leads the scholars to reflect on the factors that may influence the development effects of urban rail transit. Different theories were proposed and various factors were nominated. Unfortunately, however, there has been no systematic analysis that tests these factors.

This study takes on the challenge of studying the role of exogenous factors, including both neighborhood conditions and transit features, on the densification effects of urban rail transit. It examines the effects of the newly established urban rail transit lines on the population and housing densification in four metropolitan regions in the United States, from 1990 to 2010. To answer the research questions, this study applies a mixed methodology of spatial analysis and regression analysis. The main findings are summarized below.

1) The general presence of the land use effects of urban rail transit

Just as previous studies suggest, there is no consistent finding on the direct impact of a new rail transit system on density change in the surrounding neighborhoods. Among the four case regions this study selects, only the Green Line in Washington, D.C. shows statistically significant direct densification effect on population densification. The Orange Line in Chicago seems to marginally significant in imposing population densification effect. In the other two case regions, Denver and Los Angeles, the new investments on urban rail transit systems are missing evidence on their impacts on directing density increases.

2) Internal factors: the impacts of the transit features

Previous studies proposed that different types of rail transit may cause different development effects. Since heavy rail has a larger passenger capacity and higher travel speed, it is believed to be more effective in making development impacts. This study seems to support this argument. In the Los Angeles case, where both heavy rail and light rail lines are present, the Red/Purple Line, which is a heavy rail (i.e. subway) line, shows more densification impacts in the surrounding neighborhoods than the Blue and the Green Lines, both of which are light rail lines. Although we cannot make a general inference from just one single case, this is a piece of empirical evidence that contributes to this topic. However, we should also be cautious on making causal inference from such findings. Due to the higher capital costs of heavy rail, it is also possible that transit planners tend to place heavy rail lines where they expect to see high density or densification trend so that the high costs can be justified by high ridership. To know about the different impacts these two types of rail transit make on neighborhood densification, more direct evidence is needed.

Other transit-related features that are found to be influential factors regarding the densification effects include the years of operations of a station and the number of parking spots at a station. The longer the station has been in service, the more likely we would observe densification effects in the surrounding neighborhoods. The more parking spots are available at a station, the more likely we would expect to see densification effects in the surrounding neighborhoods. The former one is more straightforward than the latter one. It takes time to let the rail transit projects show their development effects. Consumer response takes time; zoning change takes time; housing construction takes time. In the long run, the densification effects should be more apparent than in the short run. The relationship between parking availability and densification effects seems puzzling at the first impression. Parking is usually connected with motorized travel, which is a competitive mode against transit. More often than not, having abundant parking at a station means most riders would drive to the station rather than to live in close-by neighborhoods and walk to the station. The assumption behind the whole mechanism of densification effects caused by rail transit is that people are attracted to the station areas and would actually move into the nearby neighborhoods. Park-and-Ride stations seldom meet that assumption. One possible explanation to the seemingly odd observation that more parking at rail stations brings more densification is that these stations are not simple park-and-ride stations, but also have merits of an urban transit hub.

3) External factors: the impacts of the neighborhood conditions

Neighborhood conditions are like the soil of the seed of densification. This study finds four factors that can promote or hinder the densification effects of urban rail transit: the remoteness of the neighborhood, the pre-transit density, the income level, and the power of single-family housing owners. All these factors have been suggested by previous studies but were never tested through empirical tests until now. First, the farther a neighborhood is located from central city, the less likely the densification effect will happen because the accessibility improvement brought by the new transit station is less prominent than if it were in a more central location. Second, if a neighborhood is already built up densely even before the rail transit came into being, it is more likely to continue densification due to agglomeration effects. Third, a neighborhood will receive the most densification effects if it is neither too poor with a high concentration of poverty nor too wealthy that the housing becomes less affordable to potential residents. Lastly, a large stock of single family housing in a neighborhood usually is an indicator of strong power of NIMBYism against dense development. In that case, densification is less likely to happen.

4) Explaining the inter-metropolitan differences

The last research question this study asks is “Do exogenous factors affect density at new rail stations differently among different metropolitan regions?” The short answer is yes. We find different influential factors in different cases and the magnitude of direct and indirect impacts all vary from one case to another. If we take a second look at the densification outcomes in these four case regions, as the table below shows, we will find some interesting hints on inter-metropolitan comparisons.

Table 17 : Summary of four case regions

Metropolitan region	Rail lines	Type	Rail transit before 1990?	Population densification effects	Housing densification effects
Chicago	Orange Line	Heavy Rail	Yes	Direct	Indirect
Denver	D Line	Light Rail	No	Indirect	None
Los Angeles	Red Line Blue/Green Line	Heavy Rail Light Rail	No	Direct Indirect	None
Washington, D.C.	Green Line	Heavy Rail	Yes	Direct	Indirect

As we have mentioned in the criteria of case selection, these four cases represent two types of transit systems (heavy rail and light rail) and two types of transit investments (new system and expansion to old system). Previously we have inferred that heavy rail could be more effective in promoting densification than light rail through the single case of Los Angeles. Here we can again compare the results of the four cases and find that the rail transit systems in the two cases that show significant densification effects—Washington D.C. and Chicago, happen to be heavy rail systems as well. It is a coincidence that these two cases also had rail transit before 1990. In other words, the new investments on rail transit in the 1990s are addition to old systems in Washington, D.C. and Chicago, while the rail systems in the other two cases were built brand new. Therefore, it is also likely that the lack of direct densification effects in Los Angles and Denver is due to the lack of the network effect—that an addition to an existing system offers higher regional accessibility than a brand new system built from scratch. To single out the sole effect of the transit types and the sole effect of investment types, more cases are needed in other similar studies in the future.

In the earlier discussion about the external factors that may interfere with the densification effects of urban rail transit projects, we mentioned that general economic conditions, real estate market conditions and land use regulations are all possible factors that matter. Although this dissertation does not directly test these factors, the findings of the study indirectly shed some light on the discussion. First, the accessibility score we include in the model is one of the measures that evaluate the ease of access to jobs in the entire metropolitan area, with weighting by transit travel times. Everything else being equal, a higher accessibility score is an indicator of more employment opportunities in the region, implying of a healthier economic condition. In the regression analysis of this research, we do find that accessibility is positively associated with densification in all four case regions, although it is only statistically significant in one of the cases—Denver. This observation suggests that metropolitan areas with good economic conditions tend to facilitate densification effects. Second, the real estate market condition in each of the four case regions included in this study varies. The housing market in Denver is probably looser than other three case regions. Our analysis results show that the housing densification effect is the weakest in Denver, an expected result that supports the theory that loose real estate market condition is a negative factor in fostering densification. Thirdly, in all four cases, we find that housing densification is less prominent than population densification in general. Given that population densification and housing densification are both indicators of residential densification, such a mismatch between the two densification effects indicates the possible barriers in land use regulations that prevent housing densification to catch up with population densification. Finally, there are many other possible relevant factors at the metropolitan level that this research (and any of the previous studies) did not touch, such as the political attitude towards public investments, the weather and typology of the regions, to name a few. Studies that thoroughly investigate these factors will contribute to the literature on this topic.

5) Policy implications and intervention strategies

The findings of this research are informative to transit planners in their future practice with regard to site selection and the prediction of densification effects of new rail transit projects. The absence of the direct densification effects of urban rail transit in most cases suggests that introducing a rail transit does not always cause neighborhood densification. Instead, in most cases, the densification impacts of rail facilities work through interactions with exogenous factors such as transit features and neighborhood conditions around stations. For those who expect to use transit to stimulate compact development, this finding means that careful planning and site selection decisions need to be made in order to maximize the densification effects. When feasible, heavy rail maybe more likely to stimulate densification than light rail. In terms of the influences of the contextual factors, **densification effects are more likely to be observed near a new urban rail transit station/line, if it is part of an established rail network, located in moderate-income neighborhoods with a low poverty rate, not too far away from downtown, with a pre-existing pattern of compact development and not dominated by single-family housing units.** That being said, neighborhoods that need rail transit service the most, such as extremely low-income neighborhoods with higher poverty rates, may not fall in the category that fosters the densification effects. In that case, planners and public policy makers may need to implement complementary economic development strategies and programs to help promote the densification in the neighborhoods, if densification is one of the planning goals.

Based on the findings on the densification effects and their relevant contextual factors, this study attempts to link the densification outcomes with the types of station areas, or, the station typology. It selects key neighborhood features that are important to the densification effects from individual case regions and categorizes the stations into several types based on these neighborhood features. Using the Washington, D.C. case as an example, it experiments with using radar charts to visualize station typology and the potential densification outcomes. The coordinates on the four axes of such radar charts are designed to represent the desirability of the neighborhood condition. Therefore, it is possible to predict the likelihood of potential densification effect by looking at the sizes of the covered area on those radar charts. Station areas with at least two desirable factors (or covered more than half of the diamond area on the radar chart) are more likely to experience densification effect over time. Whether this could be a general rule, however, would require more evidence from other rail systems. Presenting the densification prediction using the radar charts is an easy and straight-forward way to convey complex information with citizens in the planning process as well. This technique of data visualization could be useful in community hearings where transit planners can explain to the audience the relationship between multiple exogenous factors and potential densification outcomes of a proposed new rail transit service in the neighborhood.

6) Limitations and future research directions

There are a number of limitations of this research, which suggest possible directions of continuing the research on this topic. First of all, this study only looks into the residential densification outcomes as the measures of densification effects, which leaves out commercial densification and employment densification, both of which are important issues to investigate. Second, this study focuses more on the quantifiable factors, paying less attention on the factors that are not readily quantifiable, such as land use regulations, political environments, the process of transit planning, community participation, and so forth. A supplementary study that conducts case studies using qualitative analysis will help evaluate the influences of those factors on the densification effects of urban rail transit investments. Analyzing the stories behind the best-case scenarios and worst-case scenarios of the densification outcomes of new rail transit is another research exercise that will contribute to this discussion. Thirdly, densification is a process that takes time. Future studies that keep track of the densification trend over time in the neighborhoods served by transit will help us to better understand the dynamics and mechanisms of the densification effects caused by urban rail transit. Lastly, Chapter 7 of this research experiments with visualizing the connection between station typology and the densification outcomes of urban rail transit projects. It proposes using the radar charts, for their advantage in visually presenting complicated densification factors in a straightforward way, to be used as a tool for improving the communication between planners and residents. In future studies, we can try this method with more case regions to find the best-fitted parameters that would work in predicting densification effects.

Bibliography

Allen, J. G. (1986). Public-private joint development at rapid transit stations. *Transportation Quarterly, 40*(3), 317-331.

Alonso, W. (1964). *Location and land use: Toward a general theory of land rent*. Cambridge, MA: Harvard University Press.

American Public Transportation Association. (2012). *2012 Public Transportation Fact Book*. Washington, D.C.: American Public Transportation Association.

Anas, A. (1979). The Impact of Transit Investment on Housing Values: A Simulation Experiment. *Environment and Planning A, 11*(3), 239-255.

APTA. (1994). Glossary of Transit Terminology. Retrieved from http://www.apta.com/resources/reportsandpublications/Documents/Transit_Glossary_1994.pdf

Armstrong, R. J. (1994). Impacts of commuter rail service as reflected in single-family residential property values. *Transportation Research Record, 1466*, 88-97.

Armstrong, R. J., & Rodriguez, D. A. (2006). An Evaluation of the Accessibility Benefits of Commuter Rail in Eastern Massachusetts using Spatial Hedonic Price Functions. *Transportation, 33*(1), 21-43.

Athey, S., & Imbens, G. W. (2006). Identification and Inference in Nonlinear Difference-in-Differences Models. *Econometrica, 74*(2), 431-497.

Atkinson-Palombo, C. (2010). Comparing the Capitalisation Benefits of Light-rail Transit and Overlay Zoning for Single-family Houses and Condos by Neighbourhood Type in Metropolitan Phoenix, Arizona. *Urban Studies, 47*(11), 2409.

Badoe, D. A., & Miller, E. J. (2000). Transportation-land-use interaction: empirical findings in North America, and their implications for modeling. *Transportation Research Part D: Transport and Environment, 5*(4), 235-263.

Baldassare, M. (1981). The Effects of Household Density on Subgroups. *American Sociological Review, 46*(1), 110-118.

Baum-Snow, N., & Kahn, M. E. (2005). Effects of Urban Rail Transit Expansions: Evidence from Sixteen Cities, 1970-2000, *Brookings-Wharton Papers on Urban Affairs*.

Besser, L. M., & Dannenberg, A. L. (2005). Walking to Public Transit: Steps to Help Meet Physical Activity Recommendations. *American Journal of Preventive Medicine, 29*(4), 273-280.

Bhatta, S. D., & Drennan, M. P. (2003). The Economic Benefits of Public Investment in Transportation: A Review of Recent Literature. *Journal of Planning Education and Research, 22*(3), 288-296.

Black, W. R., & Lane, B. W. (2012). The Role of Transit in the Development of Urban Areas of the United States. In T. Hass (Ed.), *Sustainable Urbanism and Beyond*. New York, NY: Rizzoli International Publications.

Bollinger, C. R., & Ihlanfeldt, K. R. (1997). The Impact of Rapid Rail Transit on Economic Development: The Case of Atlanta's MARTA. *Journal of Urban Economics, 42*(1997), 179-204.

Bowes, D. R., & Ihlanfeldt, K. R. (2001). Identifying the Impacts of Rail Transit Stations on Residential Property Values. *Journal of Urban Economics, 50*(1), 1-25.

Bramley, G., & Power, S. (2009). Urban form and social sustainability: the role of density and housing type. *Environment and Planning B: Planning and Design, 36*(1), 30-48.

Brown, B. B., & Werner, C. M. (2007). A New Rail Stop: Tracking Moderate Physical Activity Bouts and Ridership. *American Journal of Preventive Medicine, 33*(4), 306-309.
California Department of Transportation. (2002). *Statewide Transit-Oriented Development Study: Factors for Success in California*.
Card, D., & Krueger, A. B. (1994). Minimum Wages and Employment: A Case Study of the Fast-Food Industry in New Jersey and Pennsylvania. *The American Economic Review, 84*(4), 772-793.
Cervero, R. (1989). *America's Suburban Centers: The Land Use-Transportation Link*. Boston: Unwin Hyman.
Cervero, R. (1994a). Rail Transit and Joint Development: Land Market Impacts in Washington, D.C. and Atlanta. *Journal of the American Planning Association, 60*(1), 83 - 94.
Cervero, R. (1994b). Transit-Based Housing in California: Evidence on Ridership Impacts. *Transport Policy, 1*(3), 174-183.
Cervero, R. (2004). *Transit Oriented Development in America: Contemporary Practices, Impacts, and Policy Directions*. Paper presented at the International Planning Symposium on Incentives, Regulartions, and Plans--The Role of States and Nation-States in Smart Growth Planning. Retrieved from http://www.smartgrowth.umd.edu/InternationalConference/ConferencePapers/Cervero_AmericanTOD_DateNA.pdf
Cervero, R., & Duncan, M. (2002). Transit's Value-Added Effects: Light and Commuter Rail Services and Commercial Land Values. *Transportation Research Record: Journal of the Transportation Research Board, 1805*(-1), 8-15.
Cervero, R., & Kockelman, K. (1997). Travel Demand and the 3Ds: Density, Diversity, and Design. *Transportation Research Part D: Transport and Environment, 2*(3), 199-219.
Cervero, R., & Landis, J. (1997). Twenty Years of the Bay Area Rapid Transit system: Land Use and Development Impacts. *Transportation Research Part A: Policy and Practice, 31*(4), 309-333.
Cervero, R., Sandoval, O., & Landis, J. (2002). Transportation as a Stimulus of Welfare-to-Work--Private versus Public Mobility. *Journal of Planning Education and Research, 22*(1), 50-63.
Chicago "L".org. (2011). The CTA Reinvents Itself: The "L" Heads Into the 21st Century (1990-present). Retrieved April 14, 2011, from http://www.chicago-l.org/history/index.html#history
Clower, T. L., & Weinstein, B. L. (2002). The impact of Dallas (Texas) area rapid transit light rail stations on taxable property valuations. *Australasian Journal of Regional Studies, 8*(3), 389-400.
Coulton, C. J., Chow, J., Wang, E. C., & Su, M. (1996). Geographic Concentration of Affluence and Poverty in 100 Metropolitan Areas, 1990. *Urban Affairs Review, 32*(2), 186-216.
De Bruijn, H., & Veeneman, W. (2009). Decision-Making for Light Rail. *Transportation Research Part A: Policy and Practice, 43*(4), 349-359.
Denver Regional Transportation District. (2013a, January 2013). Central Corridor Light Rail Line: Facts & Figures. Retrieved March 20, 2013, from http://www.rtd-denver.com/FF-CentralCorridorLRT.shtml
Denver Regional Transportation District. (2013b, Feburary 2013). Facts & Figures. Retrieved March 20, 2013, from http://www.rtd-denver.com/factsAndFigures.shtml
Denver Regional Transportation District. (2013c, January 2013). Southwest Corridor Light Rail Line: Facts & Figures. Retrieved March 20, 2013, from http://www.rtd-denver.com/FF-SouthwestCorridorLRT.shtml
Dittmar, H., & Ohland, G. (Eds.). (2004). *The new transit town: best practices in transit-oriented development*. Washington, D.C.: Island Press.
Douglas, G. C. (2010). Rail Transit Identification and Neighbourhood Identity. Exploring the Potential for 'Community-Supportive Transit'. *Journal of Urban Design, 15*(2), 175.

Duany, A., Plater-Zyberk, E., & Speck, J. (2001). *Suburban Nation: The Rise of Sprawl and the Decline of the American Dream*. New York: North Point Press.

Dueker, K., & Bianco, M. (1999). Light-Rail-Transit Impacts in Portland: The First Ten Years. *Transportation Research Record: Journal of the Transportation Research Board, 1685*(1), 171-180.

Dukakis Center for Urban and Regional Policy. (2010). *Maintaining Diversity in America's Transit-Rich Neighborhoods: Tools for Equitable Neighborhood Change*. Boston: Northeastern University.

Dunphy, R. T., & Fisher, K. (1996). Transportation, Congestion, and Density: New Insights. *Transportation Research Record, 1996*(1552), 89-96.

Ewing, R. (1995). Beyong Density, Mode Choice, and Single-Purpose Trips. *Transportation Quarterly, 49*(4), 15-24.

Ewing, R., & Cervero, R. (2001). Travel and the Built Environment: A Synthesis. *Transportation Research Record: Journal of the Transportation Research Board, 1780*(-1), 87-114.

Ewing, R., & Cervero, R. (2010). Travel and the Built Environment. [doi: 10.1080/01944361003766766]. *Journal of the American Planning Association, 76*(3), 265-294.

Federal Transit Administration. (2009). National Transit Database. Retrieved November 19, 2010: http://www.ntdprogram.gov/ntdprogram/data.htm

Florida, R. (2003). Cities and the Creative Class. *City & Community, 2*(1), 3-19.

Fotheringham, A. S., & Rogerson, P. A. (2009). *The SAGE Handbook of Spatial Analysis*: SAGE Publications Limited.

Gannon, C. A., & Dear, M. J. (1975). Rapid transit and office development. *Traffic Quarterly, 29*(2).

Garrett, M., & Taylor, B. (1999). Reconsidering Social Equity in Public Transit. *Berkeley Planning Journal, 13*, 6-27.

Garrett, T. (2004). *Light Rail Transit in America: Policy Issues and Prospects for Economic Development*. St. Louis, MO: Federal Reserve Bank of St. Louis.

Gatzlaff, D. H., & Smith, M. T. (1993). The Impact of the Miami Metrorail on the Value of Residences near Station Locations. *Land Economics, 69*(1), 54-66.

Giuliano, G. (1995). The Weakening Transportation-Land Use Connection. *Access, 6*(Spring 1995).

Glaeser, E. L., Kahn, M. E., & Rappaport, J. (2008). Why Do the Poor Live In Cities? The Role of Public Transportation. *Journal of Urban Economics, 63*(2008), 1-24.

Gomez-Ibanez, J. A. (1985). A Dark Side to Light Rail? The Experience of Three New Transit Systems. *Journal of the American Planning Association, 51*(3), 337-351.

Gordon, P., & Richardson, H. W. (1997). Are Compact Cities a Desirable Planning Goal? [doi: 10.1080/01944369708975727]. *Journal of the American Planning Association, 63*(1), 95-106.

Green, R. D., & James, D. M. (1993). *Rail Transit Station Area Development: Small Area Modeling in Washington, D.C.* Armonk, NY: M.E. Sharpe.

Grengs, J. (2002). Community-Based Planning as a Source of Political Change: The Transit Equity Movement of Los Angeles' Bus Riders Union. *Journal of American Planning Association, 68*(2), 165-179.

Grengs, J., Levine, J., Shen, Q., & Shen, Q. (2010). Intermetropolitan Comparison of Transportation Accessibility: Sorting Out Mobility and Proximity in San Francisco and Washington, D.C. *Journal of Planning Education and Research, 29*(4), 427-443.

Handy, S. (2005). Smart Growth and the Transportation-Land Use Connection: What Does the Research Tell Us? *International Regional Science Review, 28*(2), 146-167.

Handy, S., Cao, X., & Mokhtarian, P. (2005). Correlation or Causality between the Built Environment and Travel Behavior? Evidence from Northern California. *Transportation Research Part D: Transport and Environment, 10*(6), 427-444.

Hass-Klau, C., Crampton, G., & Benjari, R. (2004). Economic Impact of Light Rail: The Results of Fifteen Urban Areas in France, Germany, UK, and North America. Brighton, UK: Environment and Transportation Planning.

Heenan, G. W. (1968). The economic effect of rapid transit on real estate development. *Appraisal Journal, 36*(2), 213-224.

Hess, D. B., & Almeida, T. M. (2007). Impact of Proximity to Light Rail Rapid Transit on Station-area Property Values in Buffalo, New York. *Urban Studies, 44*(5-6), 1041-1068.

Hess, D. B., & Lombardi, P. A. (2004). Policy Support for and Barriers to Transit-Oriented Development in the Inner City: Literature Review. *Transportation Research Record, 1887*(2004), 26-33.

Huang, H. (1996). The Land-Use Impacts of Urban Rail Transit Systems. *Journal of Planning Literature, 11*(1), 17-30.

Institute for Metropolitan Studies. (1994). *Effects of Residential Density on Transit Usage and Residential Trip Generation*: San Jose State University.

Jacobs, J. (1961). *The Death and Life of Great Amerian Cities*. New York: Random House.

Jager, R. (2013, March 13, 2013). Facts at a Glance. Retrieved March 29, 2013, from http://www.metro.net/news/facts-glance/

Jenks, M., & Burgess, R. (2000). *Compact Cities: Sustainable Urban Forms for Developing Countries*. London: E. & F.N. Spon.

Jenks, M., Burton, E., & Williams, K. (Eds.). (1996). *Tha Compact City: A Sustainable Urban Form?* London: E&FN SPON.

Kahn, M. E. (2007). Gentrification Trends in New Transit-Oriented Communities: Evidence from 14 Cities That Expanded and Built Rail Transit Systems. *Real Estate Economics, 35*(2), 155-182.

Kain, J. (1968). Housing segregation, negro employment, and metropolitan decentralization. *Quarterly Journal of Economics, 82*(2), 175-197.

Kain, J. (1992). The spatial mismatch hypothesis. Three decades later. *Housing Policy Debate, 3*(2), 371-460.

Kent, F. (1997). TCRP Report 22: The Role of Transit in Creating Livable Metropolitan Communities. *Transportation Research Board, National Research Council, Washington, DC*.

Khandker, S. R., Koolwal, G. B., & Samad, H. A. (2010). *Handbook on Impact Evaluation: Quantitative Methods and Practices*: World Bank Publications.

Knaap, G. J., Ding, C., & Hopkins, L. D. (2001). Do Plans Matter? The Effects of Light Rail Plans on Land Values in Station Areas. *Journal of Planning Education and Research, 21*(1), 32-39.

Knight, R. L., & Trygg, L. L. (1977). Evidence of land use impacts of rapid transit systems. *Transportation, 6*(3), 231-247.

Kockelman, K. M. (1997). Travel Behavior as Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from San Francisco Bay Area. *Transportation Research Record, 1997*(1607), 116-125.

Lachapelle, U., & Noland, R. B. (2012). Does the Commute Mode Affect the Frequency of Walking behavior? The Public Transit Link. *Transport Policy, 21*(0), 26-36.

Landis, J., Cervero, R., & Guhathukurta, S. (1995). *Rail Transit Investments, Real Estate Values, and Land Use Change: A Comparative Analysis of Five California Rail Transit Systems*: Institue of Urban and Regional Studies, University of California, Berkeley.

Lane, B. W. (2008). Significant characteristics of the urban rail renaissance in the United States: A discriminant analysis. *Transportation Research Part A: Policy and Practice, 42*(2), 279-295.

Lee, S. (2010). Transport and the Recession: An Opportunity to Promote Sustainable Transport. *International Planning Studies, 15*(3), 213-226.

Levine, J., Grengs, J., Shen, Q., & Shen, Q. (2012). Does accessibility require density or speed? A comparison of fast versus close in getting where you want to go in U.S. metropolitan areas. *Journal of American Planning Association, 78*(2), 157-172.

Levine, J., Inam, A., & Torng, G.-W. (2005). A Choice-Based Rationale for Land Use and Transportation Alternatives. *Journal of Planning Education and Research, 24*(3), 317-330.

Lewis-Workman, S., & Brod, D. (1997). Measuring the Neighborhood Benefits of Rail Transit Accessibility. *Transportation Research Record: Journal of the Transportation Research Board, 1576*(1), 147-153.

Litman, T. (2004). *Rail Transit in America: A Comprehensive Evaluation of Benefits*. Victoria, British Columbia, Canada: Victoria Transport Policy Institute.

Litman, T. (2012). *Evaluating Public Transit Benefits and Costs*: Victoria Transport Policy Institute.

Los Angeles County Metropolitan Transportation Authority. (2010). Los Angeles Transit History. Retrieved December 28, 2010, from http://www.metro.net/about/library/about/home/los-angeles-transit-history/

Loukaitou-Sideris, A. (2010). A New-found Popularity for Transit-oriented Developments? Lessons from Southern California. *Journal of Urban Design, 15*(1), 49-68.

Luscher, D. R. (1995). The Odds on TODs: Transit-Oriented Development as a Congestion-Reduction Strategy in the San Francisco Bay Area. *Berkeley Planning Journal, 10*(1).

MacDonald, J. M., Stokes, R. J., Cohen, D. A., Kofner, A., & Ridgeway, G. K. (2010). The Effect of Light Rail Transit on Body Mass Index and Physical Activity. *American Journal of Preventive Medicine, 39*(2), 105-112.

Mackett, R. L., & Edwards, M. (1998). The impact of new urban public transport systems: will the expectations be met? *Transportation Research Part A: Policy and Practice, 32*(4), 231-245.

Maly, M. T. (2000). The Neighborhood Diversity Index: A Complementary Measure of Racial Residential Settlement. *Journal of Urban Affairs, 22*(1), 37-47.

Marshall, W. E. (2013). An Evaluation of Livability in Creating Transit-enriched Communities for Improved Regional Benefits. *Research in Transportation Business & Management*(0), 1-15.

McBrayer, D. B. (2003). *Light Rail Transit and Other Modes.* Paper presented at the Transportation Research Circular E-C058: 9th National Light Rail Transit Conference, Portland, Oregon.

McDonald, J. F., & Osuji, C. I. (1995). The effect of anticipated transportation improvement on residential land values. *Regional Science and Urban Economics, 25*(3), 261-278.

McMillen, D. P., & McDonald, J. (2004). Reaction of House Prices to a New Rapid Transit Line: Chicago's Midway Line, 1983–1999. *Real Estate Economics, 32*(3), 463-486.

Metropolitan Washington Council of Governments. (1991). *Commercial construction indicators: Fourth quarter and 1990 annual summary*. Washington, D.C.: Metropolitan Washington Council of Governments.

Miller, L. S. (2011). New billions for capital improvements. *Railway Age, 212*(1), 51.

Nelson, A. C. (1992). Effects of elevated heavy rail transit stations on house prices with respect to neighborhood income. *Transportation Research Record, 1359*, 127-132.

Nelson, A. C., Sanchez, T. L., Ross, C. L., & Meyer, M. D. (1997). Rail Transit in the Suburbs: Case Study of Transit Use in Atlanta's Affluent Northern Tier. *Journal of the Transportation Research Board, 1*(1997), 142-150.

Nelson, P., Baglino, A., Harrington, W., Safirova, E., & Lipman, A. (2007). Transit in Washington, DC: Current Benefits and Optimal Level of Provision. *Journal of Urban Economics, 62*(2), 231-251.

Newman, P. W. G., & Kenworthy, J. R. (1989). Gasoline Consumption and Cities -- A Comparison of U.S. Cities with a Global Survey. *Journal of the American Planning Association, 55*(1), 24-37.

Ong, P., & Houston, D. (2002). Transit, employment and women on welfare. *Urban Geography, 23*(4), 344-364.

Parsons Brinckerhoff. (2001). *The Effect of Rail Transit on Property Values: A Summary of Studies* (Draft). Cleveland, Ohio.

Parsons Brinckerhoff, & Quade and Douglas, I. (1996). Land Use Impacts of Transportation: A Guidebook.

Pendall, R. (1999). Opposition to Housing. *Urban Affairs Review, 35*(1), 112-136.

Pushkarev, B. S., & Zupan, J. M. (1977). *Public Transportation and Land Use Policy*. Bloomington & London: Indiana University Press.

Quillian, L. (2003). How Long are Exposures to Poor Neighborhoods? The Long-Term Dynamics of Entry and Exit from Poor Neighborhoods. *Population Research and Policy Review, 22*(3), 221-249.

Richmond, J. (1998). The Mythical Conception of Rail Transit in Los Angeles. *Journal of Architecture and Planning Research, 15*, 294-320.

Rosenberg, M. S., & Anderson, C. D. (2011). PASSaGE: Pattern Analysis, Spatial Statistics and Geographic Exegesis. Version 2. *Methods in Ecology and Evolution, 2*(3), 229-232.

Sanchez, T. W., Shen, Q., & Peng, Z.-r. (2004). Transit Mobility, Job Access and Low-Income Labour Participation in US Metropolitan Areas. *Urban Studies, 41*(7), 1313-1331.

Schimek, P. (1996a). Household Motor Vehicle Ownership and Use: How Much Does Residential Density Matter? *Transportation Research Record, 1996*(1552), 120-125.

Schimek, P. (1996b). *Land-use, Transit, and Mode Split in Boston and Toronto*. Paper presented at the Association of Collegiate Schools of Planning and Association of European Schools of Planning Joint International Congress.

Schrag, Z. M. (2006). *The Great Society Subway: A History of the Washington Metro*. Baltimore, MD: The Johns Hopkins University Press.

Schwardl, R. (2013). North & South American Subway and Light Rail Systems. Retrieved March 3, 2013, from http://www.urbanrail.net/am/america.htm

Schwieterman, J. P., & Mammoser, A. P. (2009). *Beyond Burnham: An Illustrated History of Planning for the Chicago Region*. Lake Forest, IL: Lake Forest College Press.

Shapiro, R. J., Hassett, K. A., & Arnold, F. S. (2002). Conserving Energy and Preserving the Environment: The Role of Public Transportation. Retrieved from http://www.publictransportation.com/pdf/reports/shapiro_report.pdf

Skolnik, J., & Schreiner, R. (1998). Benefits of Transit in Small Urban Areas: A Case Study. *Transportation Research Record: Journal of the Transportation Research Board, 1623*(-1), 47-26.

Smith, W. S. (1984). Mass Transport for High-Rise High-Density Living. *Journal of Transportation Engineering, 110*(6), 521-535.

Southeastern Wisconsin Regional Planning Commission. (1998, August 1998). How Does Commuter Rail Differ from Light Rail and Heavy Rail. Retrieved August 24, 2013, 2013, from http://www.trainweb.org/kenrail/Rail_mode_defined.html

Stokes, R. J., MacDonald, J., & Ridgeway, G. (2008). Estimating the effects of light rail transit on health care costs. *Health & Place, 14*(1), 45-58.

Sutherland, J. (Producer). (2010, December 27, 2010) Light Rail Transforming Cities, Guilding Development. *NPR Around the Nation*. retrieved from http://www.npr.org/2010/12/27/132283143/light-rail-transforming-cities-guiding-development

Texas Transportation Institute. (2010). 2010 Urban Mobility Report Available from http://mobility.tamu.edu/ums/

U.S. Census Bureau. (2010, 12/06/2010). American Community Survey: Geographic Definitions. Retrieved May 2, 2011, from http://ask.census.gov/app/answers/detail/a_id/8804/~/american-community-survey%3A-geographic-definitions

U.S. Census Bureau. (2011, December 27, 2011). Vintage of Geographic Areas for ACS Estimates. Retrieved February 22, 2012, 2012, from http://www.census.gov/acs/www/data_documentation/geography/

Vance, C., & Hedel, R. (2007). The Impact of Urban Form on Automobile Travel: Disentangling Causation from Correlation. *Transportation, 2007*(34), 575-588.

Vuchic, V. R. (2005). *Urban Transit: Operations, Planning, and Economics*. Hoboken, NJ: Wiley & Sons.

Wachs, M. (1993). Learning from Los Angeles: Transport, Urban Form, and Air Quality. *Transportation, 1993*(20), 329-354.

Washburn, G. (1986, July 29, 1986). Midway Rapid Transit Finally Gets on Track. *Chicago Tribune*. Retrieved from http://articles.chicagotribune.com/1986-07-29/news/8602240440_1_cost-overruns-rapid-transit-line-bond-issues

Washington Metropolitan Area Transit Authority. (2008). WMATA Joint Development Policies and Guidelines. In W. M. A. T. Authority (Ed.).

Washington Metropolitan Area Transit Authority. (2011). Metro Facts. Retrieved May 3, 2011, from http://www.wmata.com/about_metro/docs/metrofacts.pdf

Webber, M. W. (1976). *The BART Experience—What Have We Learned?* : Institue of Urban and Regional Development and Institue of Transportation Studies, University of California-Berkeley.

Weinstein, B. L., & Clower, T. L. (2002). *An Assessment of the DART LRT on Taxable Property Valuations and Transit Oriented Development*. Paper presented at the Australia & New Zealand Regional Science Association Intertional 26th Annual Conference.

Winston, C., & Maheshri, V. (2007). On the Social Desirability of Urban Rail Transit Systems. *Journal of Urban Economics, 62*(2), 362-382.

World Commission on Environmental Development. (1987). *Our Common Future*. Oxford, UK.