How Affordable are Accessible Locations?

Housing and Transportation Costs and Affordability in U.S. Metropolitan Areas with Intra-Urban Rail Service

by

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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
2020

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DEDICATION

To my family

ACKNOWLEDGMENTS

I would like to thank my advisor, Jonathan Levine, for his guidance and support and for challenging and pushing me conceptually and methodologically. I would also like to recognize my dissertation committee members, Lan Deng, David Thacher, and Joe Grengs, for their advice and direction. Throughout my doctoral studies, I have also benefitted from the great teaching by and support of the faculty in the Urban and Regional Planning Program, including Scott Campbell, Lesli Hoey, Larissa Larsen, and Martin Murray, to name a few. My studies and development would have not been possible without the support of the Taubman College of Architecture and Urban Planning and the Rackham Graduate School at the University of Michigan.

The Ph.D. process cannot be done without the support of friends and family. I could not have done this without the good friends that I have made in the Urban and Regional Planning Program. Thank you for the deep and meaningful conversations but also for the more nonsensical ones. A special thank you also to Gidon Jakar and his family, who hosted me nearly every Friday evening for four and half years for great dinners and conversations. Finally, I want to thank my family, who supported and encouraged me throughout the entire process.

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ABSTRACT

Housing affordability is a major problem for many Americans. The increase in residential rents in the past few decades, alongside stagnant and even lower incomes, is forcing households to spend a larger share of their income on housing. The high costs of housing relative to income mean that some households cannot afford non-housing goods and services like food, healthcare, and education. Within the affordability debate, lowering transportation costs by using transit is often viewed as a potential solution to affordability problems. While housing might be expensive, if transportation costs are low, the overall costs of living in a specific neighborhood might still be affordable. Hence, housing and transportation advocates call for improving public transport options that allow households to access destinations without needing a private vehicle.

In this dissertation, I examine housing and transportation costs and affordability in twenty-seven U.S. metropolitan areas with intra-urban rail systems. The objective of the study is to understand whether transit-rich neighborhoods, especially those served by rail, are affordable, with an emphasis on lower-income households. To this end, the dissertation adopts a multilevel approach to examining housing and transportation costs and affordability cross-sectionally and over time. Adopting a multilevel approach allows examining how neighborhood- and metropolitan-level factors interact with one another and affect housing and transportation costs and affordability. Neighborhoods (i.e., block groups and census tracts) are classified based on their proximity to rail and their built environments to examine how costs vary between different types of neighborhoods. Finally, affordability is calculated based on metropolitan-wide income levels to

assess whether housing and transportation costs are affordable to households at different income levels.

The results indicate that the majority of neighborhoods in the sampled metropolitan areas are affordable to median and moderate-income households. Moreover, transit-rich neighborhoods are found to be more affordable than auto-oriented neighborhoods, mainly thanks to lower transportation costs. Still, only small share of neighborhoods is affordable to households earning 50% or less of area median income. Even in transit-rich neighborhoods, the lower transportation costs typically do not translate into more affordable locations for very low-income households. This is because many households still rely on the private vehicle even in the most transit-rich neighborhoods.

Housing in transit-oriented development is expensive, in part, due to the high levels of transit job accessibility these neighborhoods offer. However, housing costs in these neighborhoods are also high because of low long-run elasticities of housing supply. Despite an increase in the demand for compact walkable neighborhoods in recent decades, land-use regulations and local opposition direct denser development to rail-station areas. As a result, a higher supply of housing in transit-oriented development is associated with higher housing costs regionwide due to induced demand for these neighborhoods. At the same time, increasing the supply of housing in alternative pedestrian-friendly and transit-rich neighborhoods has a moderating effect on housing costs in transit-oriented development as it allows separating the demand for walkable urban form from the demand for transit accessibility. Hence, rather than focusing on developing more housing only in transit-oriented development, efforts should focus on expanding the housing options in a diversity of neighborhood types both near and away from rail stations.

CHAPTER I

I. Introduction

1.1. The Problem of Housing Affordability in the US

A growing number of regions across the United States are facing a housing affordability crisis stemming from increasing housing costs alongside stagnant, and even declining, real incomes. Between 2000 and 2017, real median gross rent in the United States increased by 9.6% while real median household income decreased by 6.5%. As a result, over 38 million (or 30 percent of) American households in 2016 spent more than 30% of their income on housing—the standard measure of housing cost burden—up by 6.5 million households since 2001 (Joint Center for Housing Studies, 2018). Many other households might spend a smaller share of their income on housing but live in sub-standard housing or "pay" in longer-than-average commute times (Haas et al., 2006; Thalmann, 1999). Housing affordability is especially a problem in large metropolitan areas and among already-disadvantaged groups, including people of color, the elderly, and low-income renters (Joint Center for Housing Studies, 2018). As affordability issues persist, high housing costs relative to income constrain a household's ability to afford non-housing services like education, healthcare, and healthy food, resulting in greater inequalities (Stone, 2006).

The common argument in the literature and public discourse is that the current housing affordability crisis stems, to a large degree, from insufficient housing supply, especially in high-demand neighborhoods and regions (Been et al., 2019). Restrictive zoning and land-use regulations are still commonplace in most U.S. municipalities, including in rapidly-growing metropolitan areas (Gabbe, 2019). These practices, which limit the supply of housing, lead to the fast appreciation of housing costs as well as to the exclusion of lower-income households from fast-growing regions (Gyourko et al., 2013).

Acknowledging the role played by land-use regulations in the current housing-affordability landscape, several cities and states have begun introducing measures to remove zoning restrictions from high-demand areas or even entire municipalities. Minneapolis, for example, has recently passed its 2040 plan, which includes eliminating single-family zoning in the city. At the state level, the Oregon legislature passed House Bill 2001 (HB2001), which permits in larger metropolitan areas the development of duplexes in (previously) single-family lots. Similarly, the California legislature considered (and tabled) a bill—State Bill 50—which would have allowed denser development along transit corridors. The rationale behind these efforts is that removing restrictive zoning regulations will enable increasing the supply of housing, especially in high-demand areas, thus relieving some of the housing-cost increases of recent years.

Within the housing-affordability debate, public transport is viewed both as a factor that can relieve the cost burden that households experience as well as a factor that can exacerbate it. On the one hand, public transit that enables people to access employment, education, health, and other necessary services can help alleviate the affordability crisis by allowing households to reduce their transportation costs—the second-largest household expenditure, after housing, through foregoing private-vehicle ownership and use. Hence, while households may still be cost burdened by high housing costs, a location may remain more affordable due to lower transportation costs (Haas et al., 2006; Renne et al., 2016).

Accordingly, transit advocates, transportation planners, and decision makers promote the provision of rail and bus transit to low-income neighborhoods to improve the ability of those who lack access to a private vehicle to reach essential destinations (Martens, 2017; Pereira et al., 2017). Likewise, housing advocates and community organizers call for increasing affordable housing opportunities near transit, especially for low-income households (Reina et al., 2019; Tremoulet et al., 2016; Wegmann et al., 2018).

At the same time, the accessibility benefits that transit infrastructure produces are often capitalized in the housing market, leading to higher housing costs in transit-rich neighborhoods (Cervero, 2004; Duncan, 2008). Moreover, residents in transit-rich neighborhoods might still bear high transportation costs if they do not reduce auto ownership and use in places where transit does not provide a level of service that affords a modal substitution (Grengs, 2010) or due to personal preferences and household characteristics (Chatman, 2013; Smart & Klein, 2017). In other cases, accessibility benefits might result in more, rather than less, travel and therefore also higher transportation costs (Yan, 2019). As a result, residents and community leaders frequently raise concerns that extending rail services into low-income neighborhoods may increase their housing costs to the point where they outweigh (potential) decreases in transportation costs (Lung-Amam et al., 2019). If this occurs, rather than alleviating the problems associated with the housing cost burden, transit service might exacerbate the marginalization of low-income groups by increasing the overall cost of living in a neighborhood.

The tension between providing transit service to low-income groups on the one hand and higher housing costs due to localized transportation benefits on the other stands at the heart of this dissertation. Specifically, the concern is that transportation projects that improve accessibility, and thus enable reducing transportation costs, are also associated with higher housing costs, potentially to the point of increasing the overall cost of living near transit. Consequently, the ability of low-income households to access a wide range of opportunities diminishes (Nussbaum, 2009; Sen, 1999), either because they do not have sufficient disposable income to participate in activities (M. E. Stone, 2006) or because they do not have sufficient income to continue living near transit. In either case, the result is an increase in the marginalization of low-income households (Young, 2011).

Assessing whether low-income households can afford to live in transit-rich neighborhoods is, therefore, crucial from the perspectives of housing and transportation policy and justice. The goal of providing better transit service is not an end in itself but rather a means to improving low-income household's economic and social opportunities. Hence, if achieving the transit-accessibility goal comes at the cost of decreasing overall location affordability, then improving accessibility might not be as equitable as first perceived.

1.2. Research Gaps

This dissertation makes three main contributions to the location affordability (i.e., housing and transportation affordability) debate. First, the dissertation adds to the literature linking housing supply to housing costs by identifying the effect of metropolitan-level housing supply in different types of neighborhoods on housing costs at the neighborhood level. Second, the dissertation adopts a multilevel and longitudinal approach and distinguishes between neighborhoods with different built environments both near and away from rail stations. This approach allows examining how costs and affordability vary by neighborhoods while controlling for metropolitan-level variations that may be related to costs and affordability at the neighborhood level. Third, the dissertation focuses on neighborhood- rather than household-level affordability, which allows asking whether transit-rich neighborhoods are affordable, especially to low-income groups. Combined, these contributions have implications for the policy solutions that are developed toward alleviating the housing-affordability problem.

Housing rent and affordability are typically understood as factors of the housing unit and local—neighborhood—characteristics. In particular, research has examined how housing costs and affordability are related to neighborhood built-environment characteristics (Bereitschaft, 2019; Dewita et al., 2019; Song & Knaap, 2004), the quality of schools (Downes & Zabel, 2002; Gibbons & Machin, 2008), proximity to green spaces (Crompton, 2001; Luttik, 2000), neighborhood opportunity (Acevedo-Garcia et al., 2016), and proximity to transit (Cervero, 2004; Duncan, 2008; Smart & Klein, 2017). These studies have been invaluable to our understanding of the localized properties that lead to the observed variations in costs and affordability between neighborhoods.

Yet, the emphasis on housing-unit and neighborhood-level traits also fails to recognize larger-scale—metropolitan, regional, and national—factors and processes that shape costs and affordability directly through their effect on housing-unit factors as well as indirectly, through their effect on neighborhood-level characteristics. For example, housing costs might be higher in neighborhoods that have better access to (and access to higher quality) parks and green spaces than in other neighborhoods. However, costs may also be associated with the supply of parks at the municipal or regional levels. Consequently, failing to account for these higher-level factors may lead to overestimating the effect size that is assigned to the association between access to a park at the neighborhood level and house cost and affordability.

In the context of this dissertation, accounting for metropolitan-level factors is important for correctly estimating the relationships between neighborhood types and proximity to rail stations on the one hand and costs and affordability on the other hand. Indeed, extensive research exists that examines how metropolitan-level factors of housing supply, mainly land-use regulations, affect house prices (Glaeser et al., 2008a; Gyourko et al., 2013; Mayer & Somerville, 2000; Quigley & Raphael, 2005). In addition, several recent location-affordability studies employ multilevel models to control for regional variations, for example in the context of the relationship between neighborhood opportunity and housing and transportation affordability (Acevedo-Garcia et al., 2016), and to control for the share of the regional population living near fixed-route transit for an analysis of transportation costs (Renne et al., 2016). However, housing and transportation metropolitan-level characteristics have not been used in studies on housing rent, especially in relation to transportation infrastructure or within the location affordability debate.

Controlling for variations between metropolitan areas and incorporating housing-related metropolitan-level characteristics in an analysis of housing costs is necessary since costs at the neighborhood level are also a function of housing demand and supply at the metropolitan (and national) level. Previous research has identified a high demand for walkable, mixed-use neighborhoods (Fishman, 2005; Myers & Gearin, 2001). Nevertheless, many households with similar tastes also find that they cannot fully satisfy their neighborhood preferences where supply for pedestrian-friendly environments is limited (Levine & Frank, 2007; Levine et al., 2005) or unaffordable (Tremoulet et al., 2016). Accommodating these and other housing preferences can only be achieved at the metropolitan level by allowing households to choose from a wide range of neighborhood types.

In a similar vein, localized transportation benefits in the form of transit job accessibility are, to a large degree, a function of regional transportation services, regional urban form, and the link between the two. Transit-based accessibility is a product of regional transit level of service, as more frequent, faster, and spread-out service allows reaching more destinations compared to a less-frequent, slower, and limited transit service. In addition, transit is more efficient, and accessibility is higher, in denser metropolitan areas in which housing and employment are placed closer together (Levine et al., 2019).

With the exception of Smart and Klein (2017), however, studies on housing and transportation costs and affordability use proximity to transit as a proxy for localized accessibility benefits rather than transit accessibility as a direct measure of benefits. While the former is a function of distance to a station and neighborhood built-environment characteristics, the latter is a function of regional transit services and urban form. Since the ability to reduce transportation costs depends, in part, on the potential to reach destinations using transit, housing costs and affordability studies should also account for the regional accessibility benefits that are associated with transit.

Finally, in the context of location affordability research in the US, studies have typically defined affordability relative to a household's income. This approach is necessary for evaluating whether households in different neighborhood types and from different income groups are cost burdened. Yet, a household-level measure does not provide information on why a household might experience lower affordability; a household may be cost burdened due to lower income, higher housing costs, or a combination of the two. Moreover, a household might elect to spend a larger share of its income on housing in order to locate in a neighborhood that better meets its preferences, for example, for better schools. As a result, despite evidence that households in transit-oriented development spend a smaller share of their income on housing and transportation than in other rail-oriented neighborhoods, we do not know whether TODs are affordable to lower-income households. Instead, this dissertation adopts a neighborhood-level affordability measure, which calculates cost burden as the median or average neighborhood expenditure relative to a common regional income level. This neighborhood affordability approach allows asking whether neighborhoods with different built environments near and away from rail stations are affordable to households from different income levels.

1.3. Study Approach

1.3.1. Research Questions and Main Arguments

In this dissertation, I examine how housing and transportation costs vary between neighborhoods with different built-environment characteristics near and away from rail stations in U.S. metropolitan areas. The underlying motivation for the research is to examine whether transit-rich neighborhoods, especially via rail, are affordable to lower-income households. To this end, the analysis is directed by four main questions:

1. How have housing costs and affordability changed between 1980 and 2017 in neighborhoods with different urban environments (i.e., densities) near and away from rail stations in U.S. metropolitan areas?
2. How do housing costs vary between neighborhoods with different urban environments (i.e., density and walkability), distance to a rail station, and levels of transit-based job accessibility in U.S. metropolitan areas with varying supplies of housing in different neighborhood types?
3. How do transportation costs vary between neighborhoods with different urban environments, distance to a rail station, and levels of transit-based job accessibility in U.S. metropolitan areas?
4. How does location affordability (i.e., housing and transportation affordability) vary between neighborhoods with different urban environments, distance to a rail station, and levels of transit-based job accessibility in U.S. metropolitan areas?

In answering these questions, I argue that housing in rail-oriented pedestrian-friendly neighborhoods may be expensive, in part, due to a mismatch between a high demand for housing in such neighborhoods and the constrained supply of housing in them regionwide. If demand is high enough relative to housing supplies, then efforts to meet this demand by providing more housing in a single neighborhood type, namely transit-oriented development, may not be enough to alleviate current housing pressures. Instead, increasing the supply of housing only in TODs is likely to generate more demand for these neighborhoods, thus resulting in higher, rather than lower, housing costs. On the other hand, increasing the supply of housing in alternative compact and walkable neighborhood types, such as non-rail pedestrian-friendly or rail-oriented intermediate development, might moderate housing costs across different neighborhood types. This is because the greater diversity of neighborhoods allows households to choose the neighborhood type that meets their preferences the best. If this is the case, then increasing the supply of housing in neighborhoods that serve as alternatives to TODs is likely to have a moderating effect on housing costs, including in TODs. Results showing these outcome would provide a justification to shifting housing and transportation planning efforts from TODs to a larger set of neighborhood types.

1.3.2. Data, Methods, and Key Definitions

To answer the research questions, I adopt a multilevel and longitudinal approach, which allows controlling for differences between metropolitan areas, estimating the effect of metropolitan-level factors on outcomes at the neighborhood-level, and identifying changes in costs and affordability over time. The cross-sectional sections of the analysis are based on data at the block-group level that are collected for 27 U.S. metropolitan areas that provided intra-urban heavy, light, and/or commuter rail service in 2015. Data for the longitudinal sections of the analysis are collected at the census tract level for the same list of metropolitan areas for the years 1980, 1990, 2000, 2012 (2008-2012) and 2017 (2013-2017). The data that were collected include information on rail stations, data on the socio-demographic characteristics of neighborhoods (i.e., block groups and census tracts), and information on transportation costs and transit-based job accessibility. These data and methods are used to examine housing and transportation costs in six types of neighborhoods and the affordability of these costs to households in three income levels.

The analysis is conducted based on a distinction between six types of neighborhoods in order to examine how costs and affordability changes with distance from rail stations and between different combinations of built-environment characteristics. The six neighborhood types include:

- *Transit-oriented development* (TOD): These are neighborhoods that are characterized by relatively high housing-unit densities and levels of walkability within walking distance of a rail station.

- *Non-rail pedestrian-friendly development*: These neighborhoods are similar to TODs in that they are characterized by relatively high housing-unit densities and levels of walkability, yet they are not within walking distance of a rail station.

- *Rail-oriented intermediate development*: These are neighborhoods with either high housing-unit densities or high levels of walkability within walking distance of a rail station.

- *Non-rail intermediate development*: These neighborhoods are similar to rail-oriented intermediate development in that they are characterized by either high housing-unit densities or high levels of walkability, yet they are not within walking distance of a rail station.

- *Transit-adjacent development*: These are neighborhoods that are characterized by relatively low housing-unit densities and levels of walkability within walking distance of a rail station.

- *Auto-oriented developments*: These neighborhoods are similar to transit-adjacent development in that they are characterized by relatively low housing-unit densities and levels of walkability, yet they are not within walking distance of a rail station.

Affordability thresholds are defined to determine whether a neighborhood is considered affordable. The analysis follows the standard definitions of housing, transportation, and location affordability (Haas et al., 2006; Renne et al., 2016):

- *Housing Affordability*: Housing costs are considered affordable if a neighborhood's median gross rent does not exceed 30% of a specific income level, where income levels are set based on area median income (e.g., area median income, 80% of area median income, etc.).

- *Transportation Affordability*: Transportation costs are considered affordable if a neighborhood's estimated average transportation costs do not exceed 15% of a specific income level, where income levels are set based on area median income.

- *Location Affordability*: Location affordability refers to the combined affordability of housing and transportation costs. Accordingly, a neighborhood (i.e., location) is considered affordable if its combined housing and transportation costs do not exceed 45% of a specific income level, where income levels are set based on area median income.

1.4. Key Results

The analysis of housing and transportation costs and affordability reveals several interesting relationships between the built environment and transportation services on the one hand and housing and transportation costs on the other. Overall, median gross rent tends to be higher in neighborhoods that are within walking distance of a rail station than in their non-rail counterparts, in part due to the transportation benefits that are provided in terms of transit job accessibility. However, housing costs in TODs are high even after accounting for transit accessibility and housing costs in higher-density neighborhoods near a rail station increased at a faster pace between 1980 and 2017. These outcomes suggest that, in addition to transit service, part of the housing costs in TODs stem from their built-environment characteristics and demand for housing in these neighborhoods.

The analysis also shows that a larger share of housing units in transit-oriented development in the metropolitan area is associated with higher housing costs in TODs. At the same time, that a larger share of housing units in non-rail pedestrian-friendly development and especially in rail-oriented intermediate development is associated with a lower increase in housing costs in TODs. These results suggest that there is a latent demand for housing in TODs, which is induced once new housing is provided in TODs, thus preventing from housing costs to decrease as more units are supplied. On the other hand, increasing the supply of housing in neighborhoods that provide an alternative to TODs has a moderating effect on housing costs in TODs since it allows separating the demand for transit from the demand for pedestrian-friendly built environments.

While housing is more expensive in higher-density rail-proximate neighborhoods, these neighborhoods are also associated with lower transportation costs. The main reason behind this outcome is the very high levels of transit job accessibility in transit-rich neighborhoods, and especially in those that are served by rail. Thanks to the better accessibility in these neighborhoods, households can reduce their transportation costs by substituting car ownership with transit use. Hence, it seems that there is a tradeoff between housing and transportation costs. Moreover, the transportation-cost savings from living in a transit-rich neighborhood appear to be larger than the housing-cost appreciation near rail stations.

The implication of the outcomes from the analysis of housing and transportation costs is that, while transit-rich neighborhoods have slightly higher housing cost burdens, when combined with transportation, their location cost burden is lower than that found in the more auto-oriented neighborhood types. Overall, the majority of neighborhoods of all types are affordable at the level of area median income and even at 80% of area median income. At the same time, only a small share of neighborhoods is affordable to households earning 50% of the area median income or lower. In addition, transportation costs seem to be the main barrier preventing lower-income households from finding affordable locations. This outcome might be due to the auto-oriented nature of urban form in the US, which means that car ownership is often necessary even in transit-rich and lower-income neighborhoods.

Finally, the analysis of housing costs and affordability also shows that in many MSAs, a major contributor to the affordability crisis is the fast increase in rent, in part due to a slow supply of housing. However, the analysis also suggests that housing has become less affordable over time because incomes have increased at a much slower rate than housing costs. If lagging incomes are indeed contributing to the current location affordability crisis, then policy and planning efforts using housing and transportation solutions may not be sufficient to alleviate location unaffordability.

1.5. Dissertation Outline

The remainder of the dissertation is organized in the following order. *Chapter 2: Literature Review* brings together literature from different fields in order to identify the main factors that shape housing and transportation costs and their affordability. In reviewing these literatures, I emphasize the key arguments the authors make and the relevance of these studies to this dissertation, including methodological and theoretical considerations that might apply to the analysis.

Chapter 3: Study Design opens with a brief presentation of the theoretical framework that I adopt for the dissertation based on the literature from Chapter 2. This is followed by the presentation of the research questions and hypotheses that direct the analysis. Next, the methods and data sources are explained. The chapter ends with a brief discussion of the limitations of the analysis.

Chapter 4: Study Results comprises the main body of the dissertation. This chapter includes a discussion of the results on housing and transportation costs and affordability. First, housing costs are analyzed over time and then also cross-sectionally to identify key factors in shaping housing costs in each of the six neighborhood types. This is followed by a cross-sectional analysis of transportation costs. The third and final section of the chapter includes a cross-sectional and longitudinal analysis of housing, transportation, and location affordability in U.S. metropolitan areas, in each of the six neighborhood types, and for different income levels.

Chapter 5: Discussion links the evidence from this dissertation to broader themes in the literature and in practice in order to develop a better understanding of the relationships between urban form, transit service, and housing and transportation costs and affordability.

Chapter 6: Conclusions summarizes the main findings and arguments that are made in the dissertation and their implications to policy. In doing so, I identify avenues for future research that might help advance our understanding of location affordability as well as other ways to improve the lives of urban residents.

CHAPTER II

II. Literature Review

2.1. Housing and Transportation Costs: The Bid-Rent Approach

The classic approach to understanding the relationship between housing and transportation costs in a metropolitan area is based on the bid-bent theory (Alonso, 1964; Mills, 1967; Muth, 1969). According to the bid-rent theory, the rent per unit of land in a monocentric city declines with distance from the concentration of employment in the central business district (CBD) while transportation costs increase with distance from the CBD. The location decision of a firm or household depends on its preferences and income, which determines its ability to bid for land and bear transportation costs. This implies that a tradeoff exists between rents and transportation costs; a household may choose to spend more on transportation costs to enjoy lower housing costs (per unit of land) farther from the CBD, and vice versa. At each location, the land use that bids the highest rent (e.g., housing costs) gets to occupy that location. Under these conditions, households compete for their preferred location with other households as well as with other land uses (e.g. manufacturing, services, or retail).

Based on the assumption that, all else being equal, individuals aim to maximize their housing consumption (i.e., locate on larger lots), and given transportation-cost constraints (Alonso, 1964,

p. 26)[1], higher-income households who are able to pay high transportation costs locate in larger lots farther from the CBD, where land is relatively cheap. Low-income households, on the other hand, cannot afford the high transportation costs at suburban locations and therefore locate closer to the CBD. Aggregating from the individual, each household type will have a different transportation-cost curve depending on its income level. Low-income households are constrained by their ability to pay for high transportation costs and therefore have a steep curve. Higher-income households, on the other hand, have a flatter curve since transportation costs are less of a constraint on their location decisions.

Density—the number of housing units per area—plays a mediating role between transportation costs and housing costs. The housing-transportation cost tradeoff results in what seems to be a paradoxical outcome – high-income households locate in areas where land (per unit) is cheap while low-income households locate in areas where land is expensive. The solution to the paradox, however, is straight-forward – high-income households pay less per unit of land and therefore are able to consume more land. At the same time, low-income households overcome the high housing costs in central locations by consuming less housing (Alonso, 1964; Muth, 1971; Wheaton, 1982). In such cases, the aggregation of many small units of land through higher densities allows individuals to locate in more accessible, and therefore also more expensive locations (O'Sullivan, 2012).

[1] A basic assumption in Alonso's model is that individuals aim to maximize their satisfaction. In terms of housing, Alonso writes: "Land *q* is a good of the ordinary type. All other things being equal, the individual will prefer to have more than less of it; that is to say, he will prefer to have ample living space and not to be crowded." (p. 26)

2.2. Housing Costs: Complicating the Housing-Transportation Tradeoff

The simplicity of the bid-rent theory and its ability to describe the distribution of land uses and household types in North American metropolitan areas has contributed to its popularity. The basic theory, however, is a static one and is based on a set of assumptions that limit its applicability to real-world situations. Loosening some of the theory's assumptions by introducing dynamic market forces such as urban growth, the supply of and demand for housing, and land-use regulations, complicates the housing-transportation tradeoff and its impact on the distribution of land uses in a city. This has also been acknowledged separately by Alonso, Muth, and Mills, who provide alternative scenarios for circumstances in which the basic assumptions are not met. In what follows, I review relevant studies that build on and go beyond the classic urban economics approach to study the factors that shape housing (and in the next section, transportation) costs. These include the supply of and demand for housing, the filtering process, neighborhood amenities and transit accessibility in particular.

2.2.1. The Price Elasticity of Housing Supply

Supply and demand are the two pillars of price theory. All else being equal, an increase in supply would lead to a decrease in price, whereas an increase in demand would result in prices increasing. This theoretical conceptualization applies to housing as a good and has shaped policy approaches to providing solutions to issues around affordability. Specifically, the price elasticity of the supply of housing represents the ability of the housing market to respond to changes in demand for housing. As such, it determines whether an increase in housing demand results in an increase in the housing supplied (elastic supply) or to an increase in housing prices (inelastic supply).

Accordingly, the supply elasticity of housing can greatly affect the economic performance of metropolitan areas and a nation as a whole. Lower supply elasticities that lead to higher housing prices can constrain population and economic growth and have negative impacts on the labor market and residential mobility (Saks, 2008; Zabel, 2012). Moreover, constraining the elasticity of housing supply, for example, through land-use regulations, in response to demand shocks can amplify house price volatility (Paciorek, 2013). Finally, inelastic housing supply, alongside an increase in housing demand and wages, can lead to greater inequality as lower-income households are priced out of high-cost areas (Gyourko et al., 2013).

A large number of studies have examined the factors that advance or constrain the supply of housing and their consequent effects on housing prices (recent reviews include Dipasquale, 1999; Gyourko, 2009; Kim, Phang, & Wachter, 2012). These studies find that the price elasticity of housing supply is affected by a wide range of regional factors (Oikarinen et al., 2015; Paciorek, 2013). These include, among other things, geographic constraints (e.g. topography) (Paciorek, 2013; Saiz, 2010), land-use regulations (Glaeser & Gyourko, 2003; Glaeser et al., 2005; Mayer & Somerville, 2000), construction and labor costs, and real and expected interest rates (Blackley, 1999).

Overall, housing supply is typically found to be elastic in the long run (Blackley, 1999; DiPasquale & Wheaton, 1992; Follain et al., 1993) but much less in the short term (Follain et al., 1993; Grimes & Aitken, 2010; Topel & Rosen, 1988). Moreover, the time it takes the short-term elasticity to converge with the long-run elasticity is also important, as longer convergence times would make it harder for lower-income households to remain in an area with increasing housing prices. Harter-Dreiman (2004), for example, examined the price elasticity of housing supply in 76 U.S. MSAs between 1980 and 1998 and found that just over 20% of the gap between the price level and its long-run equilibrium value is reduced each year. From this, the author concludes that, in response to a demand shock, it would take about five years for prices to adjust to their long-run equilibrium value. With respect to housing in high-demand neighborhoods, for example near rail stations, these results suggest that in the short-run, housing prices can be expected to increase, thus increasing cost burdens for the people already living in those areas.

The lower elasticity of housing supply, especially in the short run, can also intensify house price volatility. While Davidoff (2013) did not find that variation in supply elasticities explains the severity of the housing bubble boom-and-bust of the 2000s, others have found that lower elasticities are associated with more volatile housing markets. Glaeser, Gyourko, and Saiz (2008), for example, found that during the housing boom of the 1980s, housing prices were more volatile in U.S. metropolitan areas that had less elastic housing supply. On the other hand, when a housing boom leads to higher prices in metropolitan areas with elastic housing supply, these price-booms tend to be shorter than in inelastic markets (Glaeser et al., 2008b; Grimes & Aitken, 2010).

The elasticity of the supply of land or housing is especially important for housing prices in areas of high demand. Zabel (2012), for example, suggests that a labor demand shock leads to higher housing price increases in cities with lower price elasticities of housing supply compared to cities with a high price elasticity of supply (though the difference between cities is not statistically significant). As a result, homeownership in low-elasticity/high-priced markets tends to be lower than in other markets. Similarly, Gyourko et al. (2013) examine the different appreciation levels in average house prices across U.S. metropolitan areas over time. The analysis shows that much of the variation in house prices can be explained by an inelastic supply of land in high-demand "Superstar" MSAs—locations that experience a persistent increase in house prices relative to growth in housing units—alongside an increase in high-income households at the national level. As a result, house prices in superstar MSAs, like San Francisco, appreciate at a much faster rate than the national average, leading to a change in the income distribution as lower-income households are priced out of the MSA. The analysis also finds that these relationships hold for municipalities within the same metropolitan area (Gyourko et al., 2013). This logic could also be applied to neighborhoods: as demand for specific types of neighborhoods or amenities increases, the elasticity of supply of land or housing in these neighborhoods will determine the effects on housing prices.

Land-use regulations play a major role in determining the elasticity of housing supply in a metropolitan area, as more constraints on development lead to lower elasticities and higher house prices. Alonso recognizes that zoning regulation can prevent the highest bidder from locating in a specific area. As a result, where high-bidding land-uses are disallowed, the location will be associated with lower bids (and therefore also rents). More often, however, zoning regulations restrict the maximum (or minimum) number of units allowed in a specific location (Alonso, 1964; Levine, 2010). Where densities are restricted to lower levels than under conditions of market equilibrium, the price of each housing unit increases. In accessible locations without density restrictions, individuals can compensate for the higher land costs by purchasing smaller units of land. However, where density is restricted, the maximum number of units allowed at a specific location is smaller than under market equilibrium, and the cost of each unit of land increases. In certain situations, the result may be that high-income individuals bid higher than low-income individuals (Alonso, 1964), and the latter are priced-out of a location they otherwise would have occupied.

Recent studies find that areas with more extensive land-use regulation are associated with fewer housing starts and lower elasticities. Mayer and Somerville (2000) examined housing data from 44 U.S. MSAs between 1985 and 1996 and found that areas with more constraining regulations had 45% fewer housing starts and price elasticities that are more than 20% lower than in regions with less regulation. Similarly, Quigley and Raphael (2005) find that Californian cities with more land-use regulation had lower levels of new housing construction between 1990 and 2000. Finally, Saks (2008) examined residential construction and house prices in 72 U.S. MSAs between 1980 and 2000. The analysis found that more regulated areas were associated with less residential construction.

As a result of lower elasticities and levels of housing construction, house prices in more regulated MSAs also tend to be higher (Saks, 2008). Quigley and Raphael (2005), for example, found that house prices in 407 Californian cities with more regulation were higher and increased at a faster rate between 1990 and 2000 when compared with prices in cities with less regulation. Similarly, Glaeser, Gyourko, and Saks (2006) examine changes in house price in U.S. metropolitan areas over time, between 1980 and 2000. In doing so, they evaluate how different housing-supply responses in response to increases in demand result either in increases in housing price or quantity. Their results highlight the importance of land-use regulations in shaping house price by limiting the supply of housing. Specifically, they find that house prices increase more in metropolitan areas with high restrictive land-use regulations that limit the supply of housing and population growth. On the other hand, an increase in the demand for housing in metropolitan areas with low levels of land-use regulation leads to urban growth that mitigates increases in housing prices.

Similarly, Paciorek (2013) examined the effect of land-use regulation and geographic limitations (e.g., slopes and water bodies) on new housing supply and housing market volatility in U.S. metropolitan areas. With respect to land-use regulations, the analysis finds that regulations that increase lags in the permit process and an increase the construction costs of housing lead to a lower elasticity of new housing supply. And this effect is more pronounced in denser metropolitan areas. As a result, house prices become more expensive and volatile in more regulated regions.

The regulation-price relationship, however, might vary by elasticity levels. Green, Malpezzi, and Mayo (2005), for example, estimate the supply elasticities for 45 U.S. metropolitan areas. The analysis finds that while more regulated MSAs typically exhibit lower elasticities, there is much more variation in elasticity levels among less regulated regions. The implication is that the effect of regulation on housing supply might be more significant in highly regulated regions than in less regulated ones.

Alongside land-use regulation, the durability of the housing stock also reduces the elasticity of housing supply. Specifically, several studies find that denser metropolitan areas have lower elasticities than less dense areas. Green et al. (2005), for example, find that in addition to land-use regulation, metropolitan areas with higher densities also had lower elasticity estimates and therefore higher house price increases. Similarly, Goodman and Thibodeau (2008) examine house price increase between 2000 and 2005 in U.S. MSAs. The analysis finds that the housing stocks in central cities and densely populated places are less responsive to increases in housing demand. As a result, house prices tend to increase at a faster rate in central cities and denser regions. In South East England, on the other hand, Fingleton (2008) estimated that an increase in housing supply was associated with lower house prices in 2001, and this relationship was stronger when housing was supplied through higher densities. Thus, while it might be more difficult to add more housing in already-dense areas, an increase in the housing supplied in these areas can have a moderating effect on housing prices.

While most studies tend to focus on owner-occupied single-family housing, some studies have also examined the elasticity of the supply of multi-family housing for renters. DiPasquale and Wheaton (1992), for example, find that the construction multi-family housing in the United States was very elastic between 1960 and 1989 while demand for rental units was relatively inelastic. More recently, Quigley and Raphael (2005) examined the effect of land-use regulation on the new construction and house prices of owner-occupied and rental units in 407 Californian cities between 1990 and 2000. The analysis finds that restrictive land-use regulations constrain the supply of owner-occupied housing but not of rental units. As a result, regulation has a stronger effect on the price of owner-occupied housing than on prices of rental units.

Finally, the effect of demand shocks on housing supply and price is not constrained to the area that is experiencing the increase in demand but rather spills over to neighboring areas. Fingleton, Fuerst, and Szumilo (2018), for example, estimate the effect of changes in housing supply in one location on house price and affordability in neighboring communities in England. Their results suggest that local house prices and affordability are not only a function of local supply and demand conditions but also on their dynamics in neighboring housing markets with a comparable housing stock within the same metropolitan area. Specifically, the analysis shows that a simulated increase in housing supply in Greater London area is not only associated with lower house prices in the region but also in South East England and other regions.

In sum, the literature on housing supply and prices show a complex relationship with housing demand. While housing seems to be elastic over the long run, it is less elastic in the short term because of its durability and because of limiting land-use regulation. As a result, housing prices tend to be higher and more volatile in areas that experience large increases in demand and where there are more constraints on new development. Applying these results to the context of the current research, an increase in demand for housing near rail stations can be expected to lead to an increase in housing costs in the short term until the quantity of housing supplied meets the increase in demand. From an equity perspective, the ability of a housing market to respond to fast increases in demand in the short-run can affect the cost burden experienced by existing residents.

2.2.2. Filtering

Another process through which housing supply and demand affect housing costs, especially for lower-income households, is filtering. Filtering describes the process in which, as new housing that is developed at the higher end of the market is occupied by higher-income households, and as the quality of older housing decreases, the price of older units also decreases, thus releasing them to be occupied by the next lower income group. Hence, the process is commonly viewed as the housing market's solution to problems related to housing quality and affordability (Been et al., 2019; Ratcliff, 1949; Rosenthal, 2014).

In the short run, the construction of market-rate housing can induce the migration of households within a metropolitan area as well as into a metropolitan area. As higher-income households move into the newly constructed units, the units that become available are often occupied by lower-income households even when the quality of the units has not decreased. This process may include multiple waves of moves and last a few years, resulting in better housing opportunities for higher- as well as lower-income households (Mast, 2019).

In the long run, housing units filter down and become more affordable to lower-income households as the quality of units deteriorates. Rosenthal (2014) examined what conditions make filtering an effective long-term source of housing to lower-income households. Using panel data from the American Housing Survey (AHS) between 1985 and 2001, Rosenthal calculated that housing in the United States filters down at a rate of 1.9% a year. Filtering rates, however, vary by occupancy type, as owner-occupied single-family houses tend to filter down at a slower rate than renter-occupied housing. Moreover, filtering also varies by region, as areas with a high house price inflation like the Northeast and West experience filtering rate that is slower than in the rest of the

US. Based on these results, Rosenthal concludes that filtering can produce lower-income housing in the long run.

Over the years, however, the adequacy of the filtering process to produce housing that is affordable to low-income households has been called into question, as market dynamics may constrain the degree to which older housing units are filtered down, and in some cases even counter the process and lead to price increases. Somerville and Holmes (2001), for example, use data from successive waves of the American Housing Survey (AHS) to examine the unit, neighborhood, and market factors that contribute to the filtering down or up of rental housing units in select U.S. metropolitan areas between 1984 and 1994. Among rental units that began as affordable, the authors find that 45.3% remain affordable to low-income households while 31.8% become unaffordable due to rent increases. At the same time, only 8.6% of the rental units that were unaffordable in 1984 became affordable in 1994 while 78% of the units remained unaffordable in 1994. These results suggest that filtering may be a very slow process.

Others suggest that even if filtering occurs, this does not necessarily translate to lower costs for low-income households. Zuk and Chapple (2016), for example, calculated that, based on Rosenthal's (2014) results, it would take new housing units that are built for the median-income household in the Bay Area about 15 years to filter down to households earning 80% of the median income and close to 50 years to filter to households earning 50% of the median income. What is more, as lower-rent housing units are occupied by lower-income households at a faster rate than rents decrease, the filtering down of housing units may still increase the rent-burden of low-income households (Zuk & Chapple, 2016). Such findings have led some scholars to conclude that the filtering process may be a necessary but not a sufficient condition for improving the housing opportunities of lower-income households (Fisher & Winnjck, 1951; Ratcliff, 1949).

A major critique of the filtering process is that market imperfections such as short-run inelastic housing supply, stemming in part from regulatory constraints, could constrain and slow down the filtering down of older housing units. For the filtering process to take place, the supply of new housing needs to be sufficiently higher than demand in order to reduce prices both for the group new housing is built for as well as for lower-income groups. Regulatory and market imperfections, however, may limit the ability of the market to adjust to change in demand. When the change in demand is small or slow, for example, regulatory constraints on and imperfections of the market can cause it to adjust slowly to changes in demand. Under these circumstances, a surplus of supply is crucial for the filtering process to take place (Ratcliff, 1949).

Moreover, the filtering has also been critiqued for its focus on the market's valuation of the physical deterioration of a housing unit rather than on differences in rates of deterioration or desirability (Fisher & Winnjck, 1951). In cases where demand is high, on the other hand, an increase in the supply of new housing may be insufficient to induce the filtering down of units (Fisher & Winnjck, 1951; Ratcliff, 1949). This is because the filtering down of a housing unit depends not only on its age and quality but also on the way the market values it or its location relative to its alternatives. As a result, an increase in the desirability of a housing unit or its location, for example due to the construction of a new transportation facility, can counter the effects of supply increases and lead to cost increases, even for older and lower-quality housing units. In such cases, older housing units might filter up to higher-income households even though the quality of the unit did not necessarily change (Fisher & Winnjck, 1951; Lowry, 1960).

While these explanations of filtering are based on exogenous factors like unit age, rate of deterioration, and desirability, endogenous factors like human behavior can also affect the process (Lowry, 1960). According to this understanding, the owners and dwellers of a housing unit can react to the market evaluation of a unit by adopting behavior that either accelerates or delays the desirability of a unit. Owners or dwellers, for example, can stop or slow down the deterioration of a unit by maintaining it adequately, thus slowing the filtering process by preventing the filtering down a unit. Somerville and Mayer (2003), for example, used data from successive waves of the American Housing Survey (AHS) between 1984 and 1994 to examine how government regulation affects the housing stock for lower-income households. The authors find that, in areas where governments restrict the supply of new, higher quality, suburban housing is also associated with a lower supply of rental units affordable to lower-income groups. This is because the demand for high-quality housing increases the return to maintenance and renovations, thus incentivizing landlords to upgrade their properties, causing previously-affordable units to filter up (Somerville & Mayer, 2003).

These last points have led Fisher and Winnjck (1951) and Lowry (1960) to argue that filtering should be used to describe the relative position of a housing unit, not a household, within the broader housing market. According to this definition, a unit is considered to have filtered down if its rent or price has decreased, not if it is occupied by a lower-income household. Alternatively, a housing unit might filter up if the market values the unit or its location higher than its alternatives, leading to higher prices.

Understanding filtering as a process that explains housing, rather than households, also allows applying the concept to the neighborhood scale as a way to examine the change in its position relative to the wider area it is in. At the neighborhood level, for example, the housing of an entire neighborhood can filter down as its average quality deteriorates and other locations are valued more. Alternatively, the housing of an entire neighborhood can filter up, even if its average quality deteriorates, if the location is valued high due to factors that increase its desirability, such as accessibility, walkability, or architectural quality (Fisher & Winnjck, 1951).

Examining the factors that contribute to the filtering up or down of rental units, for example, Somerville and Holmes (2001) found that neighborhood characteristics like higher neighborhood satisfaction and lower shares of affordable units were among the strongest factors contributing to a unit filtering up. The authors find weaker relationships with filtering down, though an increase in neighborhood income and rent are associated with a lower probability of filtering down, as are units in MSAs with a less concentrated stock of affordable units. Units in multi-family housing, on the other hand, are more likely to filter down. These results have led the authors to conclude that neighborhoods tend to homogenize over time as units in neighborhoods with few affordable units filter up while units in neighborhoods with more affordable units are more likely to filter down.

Finally, another important component of the housing supply literature has to do with the factors affecting a homeowner's decision whether to maintain and renovate their house or move. Potepan (1989) found that an increase in income was associated with a lower probability of home improvement whereas an increase in interest rates was associated with a higher probability of improvements. When considering more decision options, including consuming less housing, doing nothing, renovating, or consuming more housing, Montgomery (1992) found that an increase in income is associated with more renovation over doing nothing, as well as a higher likelihood of moving relative to improving existing housing. Moreover, homeowners in rapidly growing markets were also more likely to improve their existing housing rather than move to consume more housing, perhaps due to expectations for house price growth (Montgomery, 1992).

2.2.3. Demand-Side Factors: Neighborhood Built Environment

The bid rent theory suggests that the value of a house is not only a factor of its physical structure but also the attributes of its location (e.g., accessibility); the same structure will be valued differently depending on its location within the region. Indeed, Davis and Heathcote (2007) examined house prices in the United States while distinguishing between the price of the structure and the price associated with its non-physical attributes that are assumed to be location-related. Their analysis finds that between 1975-2006, the land-related factors accounted, on average, to 36% of the value of the aggregate housing stock and that the importance of land to house value has increased over time. Moreover, the magnitude of the impact of land on house prices varies between metropolitan areas, with land accounting for a larger share of house price in places like San Francisco. Davis and Heathcote (2007) conclude that the scarcity of land in desirable locations, which stems from the difficulty of producing more housing in these areas, is an important factor in increasing house prices. Their analysis, however, did not identify the types of amenities that render a location more attractive. Instead, the land-related portion of the house price was only calculated by subtracting the total price of a house by its construction costs.

Tiebout's (1956) classic paper on public goods, on the other hand, introduced the notion that residential location decisions are made based on the bundle of goods a municipality offers. According to this argument, households decide to locate in the municipality that provides the types of amenities that best fit their preferences. This demand for certain amenities means that the type and level of amenities at a specific location should be associated with residential property values, as households would be willing to pay more to receive a better bundle of amenities. Moreover, this relationship is also affected by the types and level of amenities at neighboring locations (e.g. municipalities or neighborhoods) through their impact on the demand for each location.

Individuals and households have a wide range of housing-related preferences which include, among other things, local amenities such as school quality (Downes & Zabel, 2002; Figlio & Lucas, 2004), access to parks or green spaces (Crompton, 2001; Troy & Grove, 2008), low crime levels (Gibbons & Machin, 2008; Troy & Grove, 2008), pedestrian-friendly environments, and access to employment opportunities. A large body of literature indicates that the benefits from these and other amenities are captured in house prices. In this section, I review a subset of this literature that focuses on the effect that different built-environment characteristics have on housing costs while the next section focuses on the relationship between transportation benefits and housing costs. These demand-side elements are relevant to the current research since much of the debate about costs around rail stations revolves around the built-environment characteristics of transit-oriented development. Hence, it is useful to review how different New Urbanist and Smart Growth elements are associated with house prices in general. The next section will review these elements in the context of rail-oriented neighborhoods.

The Smart Growth and New Urbanist movements, which grew in popularity since the 1980s and 1990s, aim to improve urban environments, especially in suburban locations, through more pedestrian-friendly urban design (Daniels, 2001; Katz et al., 1994). Accordingly, Smart Growth and New Urbanist efforts commonly emphasize design elements that promote more walkable and transit-focused neighborhoods, including increasing housing and street-network density, mix land-use development, and better access to transit. Several studies have examined different how these different elements affect house prices as a way to assess to what extent they are viewed as benefits that are capitalized by the housing market. A recent meta-analysis of studies that examine the relationship between New Urbanist elements and house prices, however, found that these elements often produce mixed results (Park et al., 2016). These inconclusive outcomes might stem, among other things, from different approaches for operationalizing each element or from a focus on single-family house sales as the dependent variable.

Perhaps the key component of smart growth approaches is to promote mixed-use development by introducing retail and commercial activities into predominantly residential neighborhoods. In this respect, other design elements like a more pedestrian-friendly built environment, are aimed at making it easier to interact with these non-residential destinations. Accordingly, studies have aimed to capture the cost premiums associated with the presence of mixed land uses in a neighborhood. Their results, however, are often conflicting and suggest that the effect on house prices depends on wider neighborhood characteristics. On the one hand, (Song & Knaap, 2003; 2004) found a significant and positive association between the presence of neighborhood-scale commercial land uses like retail, personal services, entertainment, health, education and other professional services and house prices in Portland, OR. On the other hand, (Diao & Ferreira, 2010) did not find a statistically significant association between land use mix and distance to destinations and single-family house prices in Boston, MA.

Other studies suggest that housing type and neighborhood built environment might mediate the relationship between mixed land uses and house prices. Park et al. (2016), for example, found that mixed land uses can have a positive and a negative effect on residential property values, depending on the type of land use and type of housing. Similarly, Sohn, Moudon, and Lee (2012) found that land use mix was positively associated with the price of multi-family units but had a negative association with the value of single-family units. And Matthews and Turnbull (2007) found that in King County, WA, pedestrian-oriented neighborhoods with highly connected street proximity to retail exhibited a positive relationship with house prices whereas in similar neighborhoods with less street connectivity the relationship was negative. In auto-oriented streets, on the other hand, proximity to retail and better street connectivity are both negatively associated with house prices.

While Smart Growth and New Urbanist designs emphasize denser housing development in smaller blocks and denser and more connected street network, studies have found that these elements are most often associated with lower house prices, especially in single-family neighborhoods (Park et al., 2016). Song and Knaap (2004), for example, examine the effects of five neighborhood design features on single-family house prices in Portland, OR and find a negative association between housing unit density and sale prices. Guo, Agrawal, Peeta, and Somenahalli (2016), on the other hand, examined the effect of different neighborhood characteristics on the price of single and multi-family housing units in Adelaide, Australia. Their analysis found that while density had a negative relationship with single-family house prices, it had a positive association with the price of multi-family housing units. Still, (Koster and Rouwendal (2012) found that in the Rotterdam City Region, both single- and multi-family house prices were largely negatively impacted by higher housing densities. Hence, the relationship between housing density and house price seems inconclusive and to vary by housing characteristics as well as wider neighborhood and metropolitan factors.

Dense street network design is often promoted as a New Urbanist goal with the assumption that the denser network would allow improving walkability. The street network design, however, has produced ambiguous results, with some designs having a positive association with house prices while others have a negative association. In their meta-analysis, for example, Park et al. (2016) find that cul-de-sacs and intersection densities have a positive effect while street density has a negative effect. On the other hand, neighborhood connectivity in terms of density and a grid street network positively affected single-family house prices in Boston, MA and this effect was stronger for houses within 800 meters of a subway or bus stop (Diao & Ferreira, 2010). Similarly, Sohn et al. (2012) examined prices of single- and multi-family houses, as well as commercial and office, uses in King County, WA with relation to four different built-environment characteristics. With respect to the street network, their analysis found that street density and the presence of sidewalks did not have an effect on single-family house prices but they were positively associated with rents in multi-family housing. These results further suggest that the effects of urbanist design on house prices vary by region and neighborhood type.

Another measure of walkability that is commonly used in the literature is the walk score, which assigns a numerical value to an address or a neighborhood based on a combination of street network characteristics and the proximity of commercial and institutional destinations. However, while walkability is a key component of smart growth strategies and New Urbanist design, empirical studies have largely found that the association with property values varies depending on neighborhood characteristics. In a study of 15 U.S. MSAs, Cortright (2009) found that walkability had a positive association with condominium and single-family house prices in 13 of them. The association, however, was stronger in more populated MSAs and those with more extensive transit systems. Within the same MSA, Boyle, Barrilleaux, and Scheller (2014) examined the association between neighborhood walkability and single-family house prices in Miami, Florida and found that, after controlling for neighborhood fixed effects, walkability loses its statistical significance.

In other cases, walkability was found to only have an effect in already walkable or dense neighborhoods. Li et al. (2014; 2015), for example, examined how overall walkability affects single-family and condominium house prices in Austin, TX between 2010 and 2012. Their analyses found that walkability had a positive effect on house prices in denser and already walkable neighborhoods but a negative effect in auto-oriented neighborhoods. Similarly, Rauterkus and

Miller (2011) examined the association between walkability and land values in Jefferson County, Alabama between 2004 and 2008. Their analysis found that walkability had a positive and significant association with land values and that this relationship is stronger in more walkable neighborhoods than in less walkable ones.

The literature reviewed up to here suggests that while each New Urbanist element, on its own, might not be associated with house price premiums, a price benefit might be found when a combination of elements is evaluated. This is because each element relies on the other built-environment characteristics to produce more attractive neighborhoods. Street network connectivity, for example, is valued more when a neighborhood includes desirable destinations that motivate individuals to take advantage of pedestrian-friendly infrastructure; without the presence of these destinations, the denser street network might be viewed as a disutility due to more crosswalks or overall traffic. Hence, it might be more useful to examine neighborhoods as a whole rather than each element separately.

Along these lines, Song and Knaap (2003) found that single-family house prices in a new urbanist neighborhood in Portland, OR were 15% higher than in a simulated traditional suburban neighborhood. Similarly, Li et al. (2014; 2015) found that the effect of walkability and sidewalk availability was positive and stronger in neighborhoods with higher densities and as level of walkability increased whereas in auto-dependent low walkability neighborhoods the effect is negative. In addition, Song and Quercia (2008) found that urban core and neo-traditional neighborhoods in Washington County, OR, which are characterized by higher densities, transit access, and mixed-use development, were more responsive to walkability and non-residential land uses. In more suburban neighborhoods, on the other hand, house prices are negatively affected by higher densities and a larger mix of land uses.

Overall, the evidence reviewed in this section indicates that New Urbanist built-environment elements to promote mixed-use and pedestrian-friendly development might be viewed as attractive but that their evaluation varies by housing type and depends on wider neighborhood characteristics. Specifically, the association between each element and housing prices seems to be stronger and positive multiple elements are simultaneously present in a neighborhood. Perhaps as a result of this, smart growth elements are often found to be valued more in denser neighborhoods that are dominated by single-family housing but to serve as a disutility in low-density single-family neighborhoods.

2.2.4. Demand-Side Factors: Transportation Infrastructure

Urban economic theory describes a transportation-housing tradeoff according to which any transportation benefits that (have the potential to) reduce travel costs are captured in land values. This relationship has shaped the research on the association between transportation investments and property values, which aims to estimate the capitalization effect of a transport project in the housing (or commercial properties) market. This literature typically takes on one of two approaches for estimating the effect of distance to a rail station on property values: a continuous distance measure (Chatman et al., 2012; Golub et al., 2012; Landis et al., 1995) or a buffer-based measure (Bowes & Ihlanfeldt, 2001; Cervero, 2004; Zolnik, 2019). In addition, based on the findings of early studies suggesting that the price premium associated with rail stations diminishes at about 1-3 miles from a station, studies often only focus on homes within a limited distance of a rail station (Cervero, 2004; Landis et al., 1995; Welch et al., 2018).

The literature on the rail proximity-house price relationship has largely confirmed that, all else being equal, residential (and commercial) property values tend to be higher near rail stations. Yet, some studies have also found that while proximity to a rail station has a positive effect on price, being too close to a station or rail tracks might be considered as a disamenity, negatively affecting home prices due to increased traffic, noise, or crime (Bowes & Ihlanfeldt, 2001; Golub et al., 2012; Pan, 2013). Moreover, the magnitude of the relationship that different studies have identified varies widely due to the adoption of different methodological approaches as well as by rail mode, housing type, and neighborhood characteristics (recent reviews and meta-analyses include Debrezion, Pels, & Rietveld, 2007; Higgins & Kanaroglou, 2016; Mohammad, Graham, Melo, & Anderson, 2013). As a result, it is hard to identify a single pattern that would explain the relationship between transport infrastructure and house prices (Welch et al., 2018). Instead, the effect of proximity to a rail station on house prices seems to vary based on the interaction of different factors, including rail level of service, house type, neighborhood income level, and neighborhood built environment. In this section, I review the literature on the association between rail and residential property values with an emphasis on the different factors that might shape this relationship.

Proximity to a rail station will produce benefits that are capitalized in the housing market if the rail system provides a service that consumers want and use (Chatman et al., 2012). Hence, each rail system—whether heavy, commuter, or light rail—can be expected to have an impact on property values based on the level of service it provides. Surprisingly, however, the vast majority of studies do not include a direct measure of level of service to capture this effect. Instead, studies only include variables like distance to a rail station, distance to a highway ramp, and distance to the central business district (CBD) as proxies for rail and auto accessibility. While omitting these proxy control variables can lead to overestimating the impacts of proximity to rail on residential property values (Debrezion et al., 2007), the effect of distance from the CBD on the relationship between proximity to a rail station on house values is not necessarily straightforward. On the one hand, Dubé, Thériault, & Des Rosiers (2013) found that rail proximity has a larger effect on home prices closer to the CBD, implying that higher levels of accessibility lead to higher home prices. On the other hand, Bowes & Ihlanfeldt (2001) found that in Atlanta, proximity to a rail station had a positive effect on single-family home prices farther from the CBD but a negative effect close to the CBD.

Other studies that compared the effect of different rail modes on property values in different metropolitan areas and on different housing types also suggest that the rail-housing relationship is shaped, in part, by the level of service that each line provides. Landis et al. (1995), for example, found that more expansive rail systems like BART in San Francisco and Trolley in San Diego had a positive effect on price. On the other hand, rail systems that provide lower levels of service either did not affect home prices (Sacramento) or even had a negative effect on price (CalTrain and San Jose light rail). Similarly, Lewis-Workman and Brod (1997) found higher price appreciation around stations of systems that provide high level of service (San Francisco BART and New York Subway) but no appreciation where rail provides small benefits, perhaps due to competition from a parallel highway (Portland MAX).

Studies that include more direct measures of rail level of service further highlight the importance of transit accessibility to analyzing and estimating home prices. Cordera, Coppola, dell'Olio, and Ibeas (2018), for example, found that accessibility has a positive effect on house prices near rail in both Rome and Santander (Spain). Similarly, Kay, Noland, and DiPetrillo (2014) found that in the New York metropolitan areas, transit-oriented developments with direct access to Manhattan had higher house prices than other TODs. From a methodological perspective, in a study of house prices near light rail in Houston, Pan (2013) found that the coefficients for rail station proximity variables become statistically not significant after accounting for access to employment centers. These studies suggest that accessibility positively affects house prices and, as a result, excluding accessibility measures might lead to an overestimation of the effect of rail on house prices.

While rail level of service is important for understanding the effect of rail proximity on house prices, studies have also found that denser multi-family units tend to appreciate more than single-family units. Duncan (2008), for example, examined the association between proximity to light and commuter rail stations in San Diego on single-family and condominium prices. His analysis found that while rail had a positive effect on the price of both single-family houses and condominiums, the effect on condominiums was almost double the effect on single-family houses. Similarly, Golub et al. (2012) found that the price of multi-family housing increased with proximity to light rail stations in Phoenix at a faster rate than the price of single-family houses. The authors thus conclude that proximity to a rail station is valued more by the residents of denser built-environments.

Moreover, the effect of rail on housing price appreciation might also depend on the interaction between housing type and rail-corridor characteristics. In a study on house prices in San Diego, Cervero (2004) found that proximity to light and commuter rail was a disamenity to single-family properties but specific corridors provided benefits to multi-family housing and condominiums. For condominiums, prices were higher closer to Coaster (commuter rail) stations, which tend to serve young professionals by providing service to downtown San Diego, and to East Line (light rail) stations. Multi-family (renter-occupied) housing, on the other hand, only appreciated around East Line stations, which serve a more working-class population with service to downtown and employment opportunities in La Mesa and El Cajon. While these results could also be interpreted as suggesting that rail tends to benefit multi-unit residential properties but provides a disamenity to single-family housing, other studies find that, in many cases, the value of single-family units also appreciates near rail stations (e.g., Armstrong Jr, 1994; Duncan, 2011; Seo, Golub, & Kuby, 2014; Zolnik, 2019).

The mediating effect that the built environment has on the rail-price relationship is further highlighted in studies that examine the effect of mixed-use and transit-oriented development (TOD) on home prices near rail. Kay et al. (2014), for example, found that proximity to TOD areas in New York City had a positive effect on housing prices. The higher price appreciation in TODs might stem, in part, from a more pedestrian-friendly environment, including better sidewalks and fewer parking opportunities (Cao & Lou, 2018). However, the mediating effect of the built environment might vary by house type. In a study of single-family house prices in Phoenix, Atkinson-Palombo (2010) found that in walkable station areas proximity to rail was a benefit for single-family houses and even more so for condominiums.

On the other hand, near auto-oriented stations, proximity to rail had a negative effect on the price of condominiums but it did not affect the price of single-family homes. Moreover, several studies find that just the sheer presence of TOD-favorable land use regulation can positively affect house prices near a rail station (Duncan, 2011), perhaps due to an increase in building activity in the area (Cao & Porter-Nelson, 2016). The results from these studies suggest that pedestrian-friendly environments near rail stations can have a positive effect on home prices, though the effect might often be small or not significant (Golub et al., 2012).

The above studies also suggest that alongside built-environment and house type characteristics, the rail-price relationship might also be mediated by socio-demographic characteristics. Indeed, studies have also found that the effect of distance from a rail station on home prices may also vary by the interaction of house type and income level. In lower-income neighborhoods, studies have found that proximity to rail positively affects the price of both single- and multi-family houses (Bohman & Nilsson, 2016; Cervero, 2004; Chatman et al., 2012; Nelson, 1992). For high-income groups, on the other hand, the effect of proximity to a rail station on house prices seems to vary by house type. While rail is positively associated with the price of condominiums (Cervero, 2004), it is often negatively associated with the price of suburban single-family houses (Bowes and Ihlanfeldt, 2001; Chatman et al., 2012; Nelson, 1992). However, the positive effect of rail on house prices in low-income areas and the negative association with price in higher-income neighborhoods is not universal. In a study on the effect of proximity to light rail stations in Buffalo, NY on single- and multi-family house prices, Hess and Almeida (2007) found a positive effect on homes in higher-income neighborhoods but a negative effect on homes in lower-income neighborhoods. These results suggest that the differential effect of rail on housing by income level also varies between regions.

Finally, several studies also find that home prices often increase even before a new rail service starts operating, suggesting that speculation can also positively affect home prices. However, these speculation effects may vary within a metropolitan area and by house type. In a study of a new light rail project in St. Paul, MN, for example, Cao and Porter-Nelson (2016) found that the announcement of a full funding grant agreement lead to the issuing of high-value building permits in both downtown St. Paul and farther along the rail corridor. On the other hand, more permits were issued for locations closer to downtown than farther along the corridor. Moreover, different house types may also react differently to the announcement of a new rail project. Zhong and Li (2016) found that the pre-operation stages of rail projects in Los Angeles had a positive effect on the price of multi-family housing but not on the price of single-family houses. Other studies, however, find that the announcement of a new rail line can also positively affect single-family home prices (Cao & Lou, 2018; Ke & Gkritza, 2019).

Moreover, the studies on the effect of project announcement on home prices suggests that in some cases, the speculation over new development near a proposed rail station might be stronger than the transportation benefits that the new rail service provides. On the one hand, Golub et al. (2012) found that while home prices appreciated from the beginning of the planning project and all through construction and operation the latter stage had the strongest effect on price sales. On the other hand, the price of single-family homes in St. Paul (Cao & Lou, 2018) and in Charlotte (Ke & Gkritza, 2019; S. Yan et al., 2012a) increased before rail service began operating but not after operation began. These results suggest that in some regions, speculation might have a stronger effect on price than rail service.

Overall, the studies reviewed in this section indicate that residential property values of housing in locations near light rail stations appreciate more than in other locations. However, the effect of proximity to a rail station on home prices is not inherent to any specific rail mode but rather depends on the interaction between a rail system and different housing types given different metropolitan and rail-corridor contexts.

This suggests that there is some type of benefit to living close to a light rail system. This benefit is presumably associated with the added accessibility provided by the light rail service, but studies that examine residential property values do not include accessibility gains as a factor in their models, so this relationship is only speculative. Alternatively, locations near transit might offer non-transportation benefits such as improved neighborhood conditions and amenities, especially if the light rail includes landscape architecture elements, bike paths and sidewalks along the corridor, or if it replaces heavy rail services. One indication for this is the higher property appreciation in housing within mixed-use, transit-oriented development areas near stations, which suggests that at least part of the appreciation in values can be attributed to neighborhood characteristics rather than to the added transportation service. Finally, the studies reviewed above only indirectly address the impacts of property appreciation on low-income households. Chatman et al. (2012) indicate in their conclusions that the increase in property values in low-income areas might lead to displacement. The rest of the studies reviewed in this section, however, do not address this issue.

The research reviewed in this section reveals a complex relationship between proximity to rail and house values. While house prices tend to increase with proximity to heavy, light, and commuter rail stations, this relationship is also mediated by rail level of service as well as the interactions between house type, neighborhood built-environment characteristics, and income levels. Overall, the research suggests proximity to rail has a positive effect on the price of multi-family rental units in lower-income neighborhoods, condominiums in higher-income neighborhoods, and in some cases also in single-family houses in auto-oriented neighborhoods. Moreover, pedestrian-friendly built-environment characteristics, and especially transit-oriented design, also increase the value of homes near rail stations, especially of multi-family houses and condominiums. Finally, at least some of the price premiums associated with rail stations are speculative, which suggests that they might have a negative effect on location affordability since they are not necessarily or directly associated with transportation cost savings.

2.3. Transportation Costs

Transportation expenses are an important component in a household's budget, often ranging from around 8% of income and up to around 25% (Blumenberg, 2003). Several factors interact with one another and explain the amount of money (and time) a household or individual spends on travel.

However, perhaps the two most important underlying factors are the mode used for travel and the distance that is traveled. Specifically, auto ownership and use tend to be much more expensive than alternative modes like transit, walking, and bicycling. In addition to transport-related characteristics, other factors have also been found to explain mode choice and travel behavior, including income, household preferences, and the built environment. In this section, I review some of the key factors that are associated with transportation costs to identify potential explanations for variation in transportation costs and affordability as they relate to this research.

As the largest transportation cost elements, auto ownership and use are the main factors explaining variations in transportation costs between households. Households that own a private vehicle spend, on average, more than ten-times more on transportation than carless households. Even among lower-income households that live in transit-rich neighborhoods, car-owner households have higher transportation costs than carless households (Smart & Klein, 2017). The largest cost-element associated with auto ownership is the cost of buying the car, though other notable expenses include insurance, maintenance, and gasoline (Blumenberg, 2003; Rice, 2004; Smart & Klein, 2017; Thakuriah & Liao, 2005). In addition, auto-ownership costs also vary between regions due to variations in the costs of gasoline and maintenance. As a result, the costs of owning a private vehicle tend to be higher in the Western Northeast regions of the United States and lower in the Midwest (Thakuriah & Liao, 2005).

Since auto ownership has a strong association with transportation costs, a large portion of the variation in transportation costs between households stems from differences in mode choice and travel behavior. Income is perhaps the strongest determinant of auto ownership. Specifically, lower-income households have lower rates of car ownership, shorter trip distances, and higher rates of using alternative modes such as transit, carpool, and walking (Rice, 2004; Sanchez et al., 2004; Smart & Klein, 2017). Based on a national sample of households, Smart and Klein (2017), for example, found that auto ownership among higher-income households is about 30% higher than among lower-income households. Even among car-owner households, higher-income households spend more on their private vehicles and their use than lower-income households (Rice, 2004). Consequently, Rice (2004) found that in California, higher-income households have transportation costs that are, on average, forty percent higher than the costs of low-income households and ten-times higher than those of extremely low-income households. Still, in some cases low-income households may be willing to increase their transportation costs by owning a private vehicle in order to access better employment opportunities, increase their income, and maintain employment (Blumenberg & Pierce, 2012; Smart & Klein, 2018).

Alongside income, auto-ownership rates and transportation costs are higher among larger households, households with children, and the number of workers in a household (Holtzclaw et al., 2002; Rice, 2004; Schimek, 1996; Smart & Klein, 2017). On the other hand, transportation costs are lower among female-headed households and people of color (Thakuriah & Liao, 2005) due to lower rates of auto ownership and higher rates of transit use that stem from lower incomes (Sanchez et al., 2004). In addition, households headed by younger individuals are also associated with lower levels of auto ownership. At the same time, younger household heads tend to drive more while older household heads drive less (Schimek, 1996).

In relation to the focus of this dissertation, mode choice and travel behavior are also closely related to the ability to reduce auto ownership and use and substitute them with transit, walking, and bicycling. Regardless of whether a household self-selects to live in transit-rich neighborhoods or lives their because other alternatives are not affordable, proximity to transit is largely associated with lower car-ownership and transportation costs compared to households in more auto-oriented neighborhoods (Frank et al., 2008; Rice, 2004; Smart & Klein, 2017).

Given the benefits of transit, transportation scholars and policy makers support the development of urban forms associated with lower levels of auto ownership and use and higher levels of transit use. Compact and pedestrian-friendly metropolitan and neighborhood urban form, which support more efficient transit service, tend to be associated with lower levels of auto ownership and use and higher levels of transit use (Buehler, 2011; Cervero & Kockelman, 1997; Frank et al., 2008). Zhou and Zolnik (2013), for example, compared the transportation costs in transit-oriented development to non-TOD neighborhoods in San Francisco while controlling for residential self-selection. Their analysis found that the built-environment characteristics of TODs are associated with lower transportation costs, but the transportation-cost savings are relatively small. On the other hand, urban sprawl and low-density auto-oriented development are associated with higher transportation costs (Sanchez et al., 2004).

Yet the potential to reduce transportation costs by substituting auto ownership with alternative modes such as transit by moving to and living in compact and transit-rich neighborhoods is not always fully fulfilled. Smart and Klein (2017), for example, only find weak evidence that households that move into transit-rich neighborhoods reduce their transportation costs after accounting for household income and composition. One reason for the weak association between moving into transit-rich neighborhoods and lower transportation costs is that households that make this move do not necessarily reduce auto ownership and use. Chatman (2013), for example, finds that while households in new housing near rail are associated with lower rates of auto ownership and use, this effect is largely due to built-environment characteristics rather than access to rail. Hence, Smart and Klein (2017), that difference in transportation costs between transit-rich and auto-oriented neighborhoods stem, to a large degree, from differences in income and household composition rather than transportation benefits.

2.4. Location Affordability

From an equity and policy perspective, housing and transportation costs are a concern if they limit a household's ability to participate in society (Sen, 1999; M. Stone, 2010; Young, 2011). Especially among lower-income households, high housing and transportation costs reduce the amount of disposable income that is available for purchasing other necessary goods and services such as food, healthcare, and education. Therefore, the affordability of a specific location, or neighborhood, to a household depends on the costs associated with living in that location and a household's income, or its ability to pay for these costs. As the largest cost element in a household's budget, housing has attracted the most attention among advocates, policy makers, and scholars. Research, in particular, aimed to estimate the severity of the housing affordability problem and identify factors contributing to it. In the past two decades, the potential tradeoff between housing and transportation costs has motivated policy and scholarship that focus on housing affordability alongside transportation. Even if housing is unaffordable, a location may still be affordable if transportation costs are considerably low.

2.2.5. Housing Affordability

2.2.5.1. Household-Level Affordability

The common measure of housing affordability calculates cost burden as a household's housing expenditure relative to the household's income. This household-level cost-to-income measure of affordability stems from policy programs that aim to identify households that need housing assistance as well as mortgage lenders and landlords (Hulchanski, 1995). The share of income that a household spends on housing that policy makers and scholars consider as excessive and warrants assistance is somewhat arbitrary (Feldman et al., 2002) and has changed over time. From as low as 20% and 25% in the 1960s the cost-burden threshold increased to 30% by the 1980s (Greenlee & Wilson, 2016; Hulchanski, 1995).

Multiple studies have found that housing cost burden is a problem that affects lower-income households more than higher-income ones and renters more than homeowners (Belsky et al., 2005; Joint Center for Housing Studies, 2018; Myers & Park, 2019; K. P. Nelson, 1994; K. P. Nelson & Khadduri, 1992; Quigley & Raphael, 2004). Feldman, Tyndall, Stern, Stackhouse, and Swan (2002), for example, found that more than two-thirds of extremely low-income renter households and a quarter of very low-income renter households in Minneapolis-St. Paul were cost burdened. Moreover, lower-income households are also more likely to experience severe housing cost burden when rent accounts for more than 50% of a household's income (Belsky et al., 2005;).

What is more, housing affordability problems for low-income renters have intensified over time. Quigley and Raphael (2004) examined changes in housing affordability in the United States between 1960 and 2000. The analysis found that housing cost burden has increased for renters more than for homeowners and lower-income households more than for higher-income households. One reason for the increase in housing cost burden among lower-income renters is a decrease in the availability of housing that is considered affordable (Belsky et al., 2005). Between 1960 and 2000, the share of rental housing units that are affordable to all income levels decreased from 83% to 62%, but the share of units that are affordable to poor households (households in the first quintile) decreased from 13% to 7% (Quigley and Raphael, 2004). The result is a shortage of housing units that are affordable to lower-income households (Feldman et al., 2002; Nelson, 1994).

The development of the housing affordability problem is a product of several processes, including, among other things, demographic changes, a change in the income distribution, and factors associated with the housing market (Bramley, 1994). Matlack and Vigdor (2008), for example, found that an increase in the number of higher-income households in the United States translated into higher housing costs and lower affordability for lower-income households. On the other hand, increasing the supply of housing can moderate the effect that income inequality had on housing cost burden. However, this effect was only found for metropolitan areas with weaker housing markets and high vacancy rates. In regions with greater income inequality and a tight housing market, an increase in higher-income households resulted in lower-income households experiencing a higher housing cost burden.

In addition, the investment strategies that landlords in different housing markets adopt may also explain some of the variation in housing cost-burden rates between higher- and lower-income households. Using the 2012 U.S. Rental Housing Finance Survey, Desmond and Wilmers (2019) found that renters in low-income and predominantly black neighborhoods pay more for housing relative to the property value that is associated with their housing. These results suggest that landlords may have different investment strategies for higher-income and lower-income neighborhoods. In higher-income neighborhoods, landlords might adopt a long-term investment strategy, which allows maintaining a thin profit margin. In lower-income neighborhoods, risk of vacancy and nonpayment might be higher. Consequently, landlords adjust by adopting a short-term investment strategy, which manifests in wider profit margins and more expensive rents relative to the value of the property.

At the neighborhood level, studies have found that built environments that are associated with higher housing costs also tend to have higher housing cost burdens. Renne, Tolford, Hamidi, and Ewing (2016), for example, examined housing and transportation costs in three types neighborhoods near rail stations in U.S. metropolitan areas. The analysis shows that transit-oriented development, the most transit-rich and walkable neighborhood type, is associated with higher housing costs and cost burdens relative to neighborhoods with lower levels of transit job accessibility or walkability. Similarly, Bereitschaft (2019) examined the association between housing affordability at the neighborhood and metropolitan scales and walkability in U.S. MSAs and found that walkability at the census tract level was associated with a higher housing cost burden. Yet the results also suggest that this relationship is mainly due to lower incomes in walkable neighborhoods rather than higher rents.

Hence, while higher housing cost burdens are popularly viewed as stemming from housing-market conditions, income may also be a major factor explaining affordability (Bereitschaft, 2019; Rodríguez-Pose & Storper, 2019; Smart & Klein, 2017). Quigley and Raphael (2004), for example, found that the increase in housing cost burden in the United States during the 1960s and 1970s is explained, to a large degree, by a decrease in income in these decades, although rents have also increased considerably during this time. Between 1980 and 2000, however, income has increased but rental units have become less affordable due to larger rent increases.

Other studies suggest that income still plays a role in housing affordability. Feldman, Tyndall, Stern, Stackhouse, and Swan (2002) identified two potential reasons for housing cost burden - land-use regulation and low incomes. To illustrate the effect of low income on housing affordability, the analysis examined the share of renter households in the Minneapolis-St. Paul region that would be cost burdened if rents were lower. The results show that even after a hypothetical reduction in rent, a large portion of lower-income renters will still face a housing affordability problem. Based on these outcomes, the authors conclude that income is a larger barrier to affordability than rent. Accordingly, alleviating the housing affordability crisis should include providing more cash assistance, including for non-housing services like food and medicine.

Similarly, Myers and Park (2019) examined housing affordability in 50 of the largest U.S. metropolitan areas between 2000 and 2016 using a constant quartile mismatch approach. The analysis shows that different dynamics between income and rent can all result in housing cost burden. In MSAs like San Francisco, San Jose, and Washington DC, incomes have increased between 2000 and 2016 though rents increased at a faster rate. On the other hand, in MSAs like Buffalo, Pittsburgh, and Miami, incomes were stable while rents have increased. Finally, in MSAs like Detroit, Atlanta, and Kansas City incomes decreased but rents have increased. Similarly, Greulich, Quigley, Raphael, Tracy, and Jasso (2004) found that U.S. metropolitan areas that experienced faster population growth between 1980 and 2000 also saw an increase in housing costs yet not in housing cost burdens, perhaps because of an increase in incomes.

2.2.5.2. Limitations of the Household-Level Measure

The household-level cost burden measure has been an important component in describing the severity of housing affordability problems, especially among lower-income households. At the same time, it has also been the target of extensive criticism, arguing that it relies on arbitrary affordability thresholds (Feldman et al., 2002; O'Dell et al., 2004). As a result, it might be inadequate for cost-burden analyses or policy decision-making (Hulchanski, 1995).

Perhaps the most common critique of the household-level cost-to-income ratio is its use of a single measure to evaluate the housing situation of households with different needs, preferences, and socio-demographic characteristics (Hulchanski, 1995; Jewkes & Delgadillo, 2013). Specifically, the household-level measure does not account for the tradeoffs many households make between cost and housing quality, neighborhood quality, and location (Belsky et al., 2005). In some cases, cost-burdened households might be making an informed decision to spend more on housing in order to reduce other costs, for example on transportation (Feldman et al., 2002), to consume better quality housing, or to access non-housing services (Quigley & Raphael, 2004). Hence, especially for middle- and high-income households, the problem of housing affordability might be inflated by a mismatch between housing preferences and expectations of housing costs (Linneman & Megbolugbe, 1992).

The issue with the household-level measure is that, when it is applied to the entire population, it does not distinguish between higher- and lower-income households that are cost burdened (Feldman et al., 2002). Consequently, the measure might fail to identify the households that are in the most need of assistance (O'Dell et al., 2004). While higher-income households might be cost burdened because of a willingness to pay higher costs to receive a better basket of amenities, lower-income households may be cost burdened because of their lower incomes rather than the quality of housing they consume (Lerman & Reeder, 1987). Hence, in addition to questions of affordability, research and policy should also account for the costs of consuming housing that meet adequate housing standards (Whitehead, 1991). In some cases, households may not be cost burdened because they are under-consuming housing since they cannot afford housing at an adequate standard (Thalmann, 1999).

The treatment of income in the household-level measure might also be problematic since it reflects transitory, rather than permanent, income (Hulchanski, 1995). As such, it reflects current, and perhaps temporary, housing decisions and income levels rather than more permanent life circumstances and long-term low-income status (Feldman et al., 2002; Linneman & Megbolugbe, 1992). Thus, a measure of permanent income, such as a specific income-level threshold, might be more adequate measure since it reflects a household's long-term affordability abilities (Bogdon & Can, 1997).

Comparing the outcomes produced by the household-level affordability measure to other affordability measures suggests that the former might overestimate the extent of the affordability problem. Lerman and Reeder (1987), for example, developed a quality-based measure of housing affordability to identify low-income households that do not have sufficient income to rent adequate housing for less than 30% of their income between 1975 and 1983 in U.S. metropolitan regions. The analysis found that the household rent-to-income ratio overestimated the share of households experiencing a housing cost burden by 20-24% compared to the quality-based approach. Similarly, Combs, Combs, and Ziebarth (1995) compared three measures of housing affordability using data for 1987 from the Panel Study of Income Dynamics. The results showed that 16.5% of the sample were considered cost burdened based on the cost-to-income ratio measure whereas the other two other measures showed slightly lower housing affordability problems.

2.2.5.3. Alternative Measures of Housing Affordability

Several alternative measures of affordability have been proposed over the years to overcome the limitations associated with the household-level cost-to-income measure as well as to provide different and broader perspectives of affordability problems. Routhier (2019), for example, examined housing insecurity in 25 U.S. metropolitan areas using an index that combines between unaffordability, crowding, poor physical conditions and forced moves. This approach allows identifying the multiple and simultaneous housing problems that renters may face. Among the four indicators, housing unaffordability is the strongest indicator of housing insecurity. Yet the analysis also found that just under a quarter of households experienced at least three of the four housing indicators.

Another common approach to overcome the limitations of the household-level cost-to-income measure is to adopt a similar formula using neighborhood-level costs and metropolitan-level incomes. This shift marks a move from a transitory-income approach to a permanent-income approach and, as such, avoids making any assumptions regarding the housing decision households make. Rather than asking whether a household is cost burdened, this approach allows asking whether a neighborhood is affordable to households at different income levels (Bogdon & Can, 1997; Saberi et al., 2017). Bogdon and Can (1997) examined housing affordability issues in the Syracuse metropolitan area using a neighborhood-level affordability measure. Their analysis shows that households with incomes below the area median income tend to spend a larger share of their income on housing, in part because of a mismatch between the number of lower-income households in the region and the number of housing units that are affordable to them.

Similarly, some scholars adopt a quality-adjusted measure and examine whether a household's income is high enough to afford housing at an adequate standard (Lerman & Reeder, 1987; Thalmann, 1999). Lerman and Reeder (1987), for example, found that some low-income households that may not be considered cost burdened under the household-affordability measure could not rent an adequate housing unit for less than 30% of their income. Along the same lines, Thalmann (1999) identified several groups of households that vary in their housing conditions. Among these are households that are not cost burdened because they under-consume housing, cost-burdened households because that can reduce their cost burden only by under-consuming housing, and households that are cost burdened even though they are under-consuming housing.

Finally, perhaps the most comprehensive alternative approach to the cost-to-income ratio is the residual-income approach (Stone, 2010; Stone, 2006). According to Stone, housing is considered unaffordable if, after accounting for housing costs, a household does not have enough income to left cover a minimal level of non-housing needs like food, education, and healthcare. This approach avoids the limitations associated with the cost-to-income measure since they account for geographic and household characteristics (Jewkes & Delgadillo, 2013). Stone finds that some very low income and larger households that are not cost burdened under the traditional approach can still be considered as a housing affordability problem since they do not have enough income left for other necessary goods. Using a similar approach, Kutty (2005) found that the vast majority of households just over or below the poverty line experience housing-induced poverty, concluding that the traditional affordability measure underestimates the housing affordability problem in the US.

2.2.6. Transportation Affordability

The persistence, and even exacerbation, of housing cost burdens has led policy makers and researchers to look outside of housing for additional solutions to affordability problems. Since transportation costs are typically the second-largest expense in a household's budget, reducing these costs are often viewed as a potential approach to reducing the overall cost burden that is associated with living in a certain location. While housing costs may be high, together with low transportation costs, a neighborhood may still be considered affordable. Specifically, transportation expenditure is typically considered affordable if it does not exceed 15% of a household's budget. But this figure can be reduced significantly if a household substitutes auto ownership and use with more affordable modes like transit. Interestingly, despite the influence that transportation costs have on a household's budget and their importance to the overall cost burden households experience, no studies have been found that focus only on transportation cost burden. Instead, transportation cost burden is only evaluated alongside housing cost burden in location affordability studies.

Following the distribution of transportation costs between transit-rich and auto-oriented locations, transportation cost burdens are also lower where transportation benefits are larger. At the metropolitan level, the households of compact regions like New York, Los Angeles, and Chicago have, on average, lower transportation cost burdens than households in auto-oriented metropolitan areas like Atlanta, Dallas, and St. Louis (Haas et al., 2006; Hamidi et al., 2016). On the other hand, studies examining neighborhood-level transportation affordability report some conflicting results; some studies find that central neighborhoods are more affordable because of lower transportation costs while others find that they are less affordable because of lower incomes. These differences seem to stem from the different approaches studies adopt for calculating affordability or classifying neighborhoods.

Several studies find that central and transit-rich neighborhoods have lower transportation cost burdens, as the bid-rent theory assumes. Hamidi et al., (2016), for example, examined transportation costs and affordability among households that qualify for HUD rent assistance in U.S. metropolitan areas. Their analysis found that households in more central locations of a metropolitan area have very low transportation-cost burdens as a share of their income while households in more auto-oriented locations had higher cost burdens. Similarly, Renne et al. (2016) examined housing and transportation costs and affordability in neighborhoods near rail stations in U.S. metropolitan areas. Their analysis found that compact walkable neighborhoods near rail were associated with the lowest transportation cost burden as share of a household's income, while low-density auto-oriented neighborhoods near rail were associated with the highest transportation cost burdens. Finally, Saberi et al. (2017) examined the distribution of housing and transportation affordability in Melbourne, Australia. As share of regional income, transportation costs are more affordable in central transit-rich neighborhoods and less affordable in suburban auto-oriented neighborhoods.

Other studies that also use household-level measures of affordability found that, in addition to a location within a metropolitan area, transportation cost burdens also vary between neighborhoods based on their socio-demographic characteristics. Haas et al., (2006), for example, found that transportation costs are the least affordable in central neighborhoods and moderate-income exurban neighborhoods. But the reasons for the high cost burdens in these neighborhoods are different in each neighborhood type. Central locations are unaffordable mainly due to the low-incomes of households in these neighborhoods. On the other hand, transportation costs in exurban locations are unaffordable due to the long commutes associated with these neighborhoods. Finally, transportation cost burdens are lowest for households in higher-income suburban neighborhoods, mainly due to the higher-incomes.

Hence, the relationship between transportation benefits (and costs) and cost burdens seems to be mediated by income. Specifically, while lower-income households tend to live in more central and transit-rich neighborhoods and spend less on transportation than higher-income households, they are still associated with higher transportation cost burdens due to their lower-incomes (Acolin & Green, 2017; Haas et al., 2006; Smart & Klein, 2017; Vidyattama et al., 2013). Based on the 15% of income threshold, only households with incomes higher than $75,000 are not cost burdened by transportation costs. For lower-income households, transportation cost burdens range from 18% of income among moderate-income households to 56% among households earning $20,000 or less (Haas et al., 2006).

These outcomes, from multiple studies, imply that even in transit-rich neighborhoods, lower-income households are not able to rely only on transit to fill all their transportation needs.

Notably, Smart and Klein (2017) examined the change in households' housing and transportation costs and affordability following a move to transit-rich neighborhoods using panel data from the Panel Study of Income Dynamics. The analysis shows that, as a share of household income, higher-income households and carless households have lower transportation cost burdens than lower-income households and households with a car. Moreover, among both higher- and lower-income households, transportation cost burdens are lower among carless households than for households in transit-rich neighborhoods or households. These results suggest that income and auto ownership have a larger influence on transportation affordability than living in a transit-rich neighborhood. This is because many households, even those with low incomes or in transit-rich neighborhoods, still own a private vehicle.

2.2.7. Location Affordability

Studying housing costs and affordability alongside transportation costs and burdens confirms the tradeoff between housing and transportation costs that the bid-rent theory assumes, highlighting the potential to improve affordability by reducing transportation costs. Specifically, accounting for transportation costs changes the pattern of neighborhoods that are considered affordable. Low transportation costs in central locations mean that neighborhoods with high housing costs can still be considered affordable. On the other hand, some suburban locations with seemingly-affordable housing emerge as unaffordable after including transportation costs due to higher auto-dependence and longer commute distances (Dewita et al., 2019; Haas et al., 2006; Mattingly & Morrissey, 2014; Saberi et al., 2017; Wang & Immergluck, 2019).

At the same time, location-affordability studies also shed light on the limitations of transportation benefits to improve affordability among lower-income households. Despite living in more central and transit-rich neighborhoods, lower-income households are still more likely to be cost burdened than higher-income households (Acolin & Green, 2017; Smart & Klein, 2017). In an analysis of twenty-eight U.S. metropolitan areas, Haas et al. (2006) found that, while low-income households tend to live in lower-cost neighborhoods, as a share of their income their cost burdens are still higher than regional average cost burdens. The analysis further finds that the main determinant of overall affordability is the association between location within a metropolitan area and transportation costs. While housing in less accessible locations is less expensive, the higher transportation costs in these neighborhoods render the location less affordable.

Auto-dependency seems to be the main barrier to location affordability among lower-income households, even in transit-rich neighborhoods. In an analysis of households in U.S. metropolitan areas, Smart and Klein (2017) found that households that move to a neighborhood with larger accessibility benefits do not reduce their transportation costs by giving up auto use. As a result, movers into more accessible locations tend to be more cost burdened than other households. Even among lower-income households, the analysis only finds a small change in auto ownership among households that move into transit-rich neighborhoods. Accordingly, the authors conclude that there is little evidence to support the location affordability hypothesis. Instead, income and the associated lower auto-ownership levels seem to be stronger determinants of location affordability.

The complicated relationships between location, income, and housing and transportation affordability have implications for residential mobility and the ability of lower-income households to access better opportunities. In a study of residential mobility between counties in all 50 U.S. states between 2008 and 2011, Greenlee and Wilson (2016) found that for the median income household, housing affordability is more important in explaining mobility within the same metropolitan area while transportation costs explain more of the variation in mobility between metropolitan areas. Yet, lower-income households aiming to move within a metropolitan area often have difficulties finding adequate housing that is affordable in safe and desirable neighborhoods (Tremoulet et al., 2016). Thus, high location cost burdens among lower-income households prevent them from accessing neighborhoods with better education and health services and social and economic opportunities (Acevedo-Garcia et al., 2016).

CHAPTER III

III. Methodology

3.1. Conceptual Framework

The dissertation adopts the urban-economics approach as the framework for studying housing and transportation costs and affordability (Figure III-1). However, the contributions of the dissertation also stem from loosening some of the basic assumptions in the bid-rent approach. My goal is to examine how real-world processes complicate the housing-transportation cost tradeoff the theory introduces (Alonso, 1964) and the implications this has to the understanding of housing and transportation costs and affordability.

According to the bid-rent theory, land values decline with distance to the central business district (CBD) while transportation costs increase with distance (Alonso, 1964; Mills, 1967; Muth, 1969). Within this framework, households (and firms) locate within a metropolitan area based on their ability to afford a specific location's combination of housing and transportation costs. Hence, a tradeoff exists between housing and transportation costs, and this tradeoff affects the locational decisions of households and firms. Assuming that both higher- and lower-income households have similar housing-consumption preferences (for consuming more housing), higher-income households will be able to increase their housing consumption by locating farther away from the CBD since they have enough disposable income left after housing to afford higher transportation costs. Low-income households, on the other hand, will not have sufficient disposable income for housing after accounting for transportation costs if they locate at a considerable distance from the CBD. As a result, low-income households tend to locate in more central areas to minimize their transportation costs while consuming less housing (i.e., fewer units of land) to compensate for the high housing costs in accessible locations.

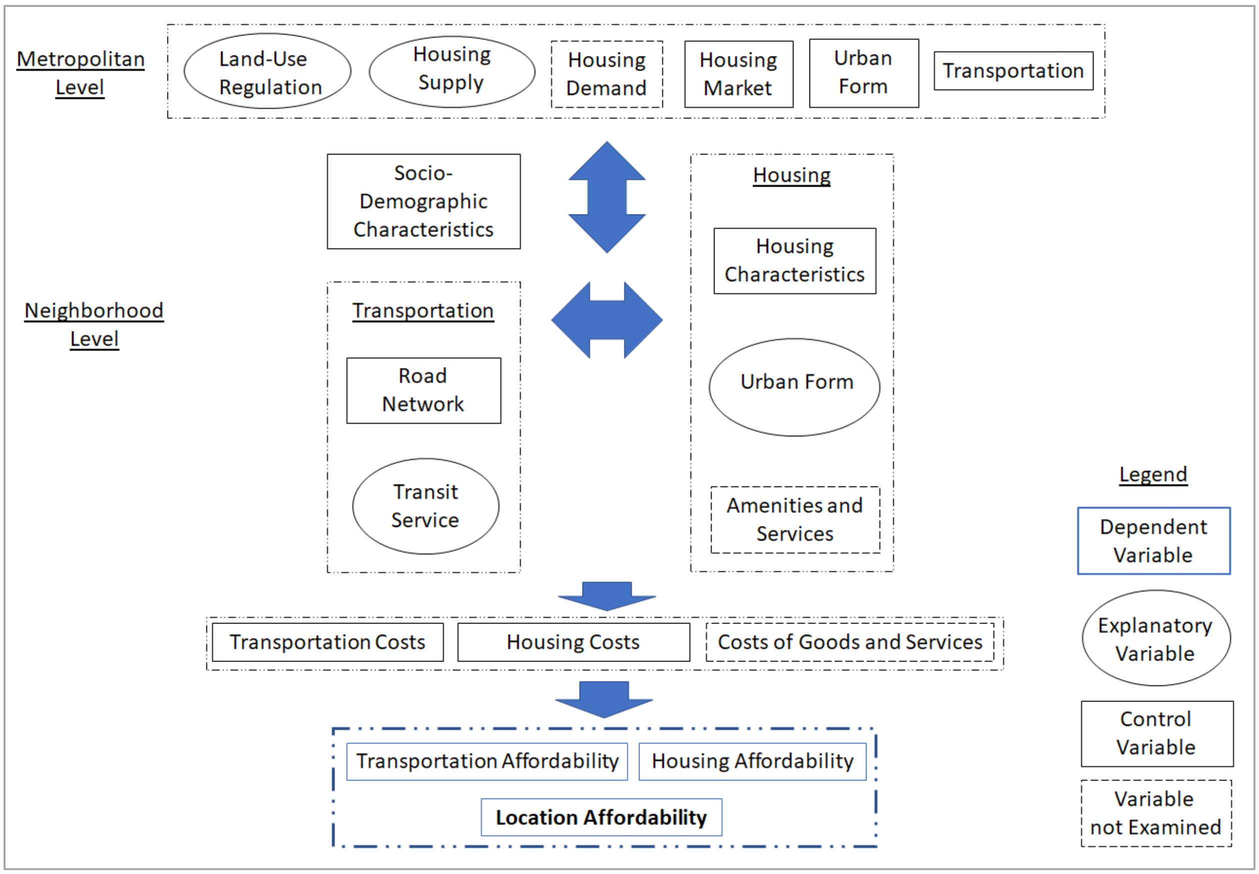

Figure III-1: Conceptual Framework

Alonso began loosening the assumptions of his theory already in his seminal book from 1964 by asking how the housing-transportation cost relationship changes if multiple employment centers are considered (i.e., polycentric cities) or given density-constraining land-use regulations. In this dissertation, I continue this discussion and examine how the interaction between housing supply at the metropolitan and neighborhood levels and the transportation benefits at the neighborhood level affect the housing-transportation cost tradeoff and what are the implications to location affordability.

Specifically, I argue that housing in pedestrian-friendly built-environments in transit-rich neighborhoods such as those found in transit-oriented development may be expensive, in part, because of their scarcity at the regional scale. Since this cost-driver is exogenous to the transport system, any cost-increases that result from it cannot be compensated by transportation-cost savings. The mechanism for moderating the cost-increases that stem from an under-supply of housing are not straightforward. Where housing has been severely under-supplied for many decades, latent demand for housing implies that increasing the supply of housing in the most demanded neighborhood type is unlikely to reduce housing costs in the short term. On the other hand, increasing the supply of housing also in similar neighborhoods regionwide can have a moderating effect on housing costs in high-demand neighborhoods by allowing households to choose between a larger set of alternatives, thus reducing the demand for any single neighborhood.

The housing-transportation cost tradeoff hypothesis suggests that housing in transit-rich locations is expected to be more expensive than in less accessible locations due to the transportation-cost savings that result from better accessibility. Indeed, research on the effect of proximity to rail stations on residential property values has largely confirmed the positive relationship between accessibility and housing costs (Debrezion et al., 2007; Higgins & Kanaroglou, 2016; Mohammad et al., 2013). Yet home-value appreciation is not equal across space, as housing in transit-oriented development near rail tends to be more expensive than in more auto-oriented neighborhoods near rail. Such housing-cost variability is commonly understood as a function of different levels of transit accessibility and additional transportation-cost savings from walkability-benefits in pedestrian-friendly neighborhoods (Atkinson-Palombo, 2010; Cao & Lou, 2018).

At the same time, the higher housing costs in transit-oriented development may also be driven, in part, by growing demand for pedestrian-friendly development, especially among young professionals and retiring baby boomers (Fishman, 2005; Myers & Gearin, 2001). Accommodating these and other housing preferences can only be achieved at the metropolitan level, by providing a wide range of neighborhood types both near and away from transit. In most U.S. metropolitan regions, however, single-family zoning restricts the supply of housing in a diverse set of neighborhood types. As a result, households are often unable to fully meet their housing preferences (Levine & Frank, 2007; Levine et al., 2005). In regions where this is the case, the latent demand for housing in specific types of built environments means that increasing the supply of housing in high-demand neighborhoods will result in housing-cost increases, not decreases (Gyourko et al., 2013).

On the other hand, supplying housing in a diversity of neighborhoods has the potential to moderate housing costs in transit-rich neighborhoods by allowing better differentiation between households based on their neighborhood preferences and therefore reducing the demand for a single neighborhood type. In the context of this dissertation, while some households prefer transit-oriented development for their transit benefits, others might prefer these locations for their pedestrian-friendly environment (Chatman, 2013). In the current state of the American metropolis, however, both transit and pedestrian-friendly preferences can be met, to a large degree, only in a small share of rail-oriented neighborhoods regionwide. To the extent that demand for housing in transit-oriented development is driven by separate preferences for transit benefits and pedestrian-friendly benefits, allowing households to achieve their housing goals through the provision of a diverse range of built-environments will have a moderating effect on housing costs in each type of neighborhood.

This framework also has implications for location affordability (i.e., the combined affordability of housing and transportation costs). Where housing demand and supply are in equilibrium, housing costs are a function of housing consumption, local amenities and the transportation benefits that are associated with a specific location (Alonso, 1964). Under these conditions, transportation-cost savings are capitalized in housing prices and overall affordability is also at equilibrium. However, where there is a mismatch between the demand for and the supply of housing in a specific neighborhood type, housing costs are higher than under conditions of equilibrium while transportation costs remain the same. Consequently, overall affordability is reduced.

3.2. Research Questions and Hypotheses

Building on the theoretical framework, housing and transportation costs and affordability are understood as a function of both neighborhood and metropolitan urban-form, housing-market, and transportation characteristics. However, to the best of my knowledge, previous studies have not examined the effects that urban form and housing stock at the metropolitan level have on housing prices, costs, or affordability at the neighborhood level, especially near rail stations. Moreover, studies on residential property values or location affordability tend to use proximity to a rail station as a measure of transportation benefits. As a result, they do not capture the full accessibility benefits associated with rail service or how these benefits might affect housing and transportation costs.

To fill these gaps, two sets of research questions are expressed to address issues regarding housing and transportation costs and affordability for low-income households near rail stations.

These questions capture the temporal characteristics of housing costs and affordability near rail stations as well as the dynamic relationships that housing and transportation costs and affordability have with neighborhood and metropolitan characteristics. Results showing that a heterogeneous housing stock has a moderating effect on housing costs near rail stations will provide further evidence for the need in dense urban environments at the metropolitan level rather than just near transit.

Temporal Changes in Housing Costs and Affordability

Question 1: How have housing costs and affordability changed between 1980 and 2017 in neighborhoods with different urban environments (e.g., densities, housing types) near and away from rail stations?

Hypothesis 1: Housing rent is expected to have increased in higher-density neighborhoods near rail stations at a higher rate than in lower-density neighborhoods and in neighborhoods that are not near a rail station. This is mainly due to a large unmet demand for housing in compact transit-rich neighborhoods. As a result, housing affordability is expected to have decreased at a higher rate in higher-density neighborhoods near rail stations, especially for lower-income groups.

However, the increase in rent in neighborhoods near rail is expected to be moderated by the share of housing units in alternative neighborhoods such as high-density non-rail or medium-density rail neighborhoods. In other words, rent is expected to increase at a higher rate in rail-oriented high-density neighborhoods within homogenous, low density, metropolitan areas. On the other hand, in metropolitan areas with a heterogeneous housing stock, the rate of change in rent is expected to be smaller since these regions have a larger supply of housing in different types of neighborhoods. In these heterogeneous regions, unmet demand for walkable neighborhoods is expected to be lower, and changes in rents are mainly due to improvements to the housing stock and transportation services.

Housing Costs and Affordability

Question 2: How do housing costs and affordability vary between neighborhoods with different urban environments and levels of transit-based job accessibility near and away from rail stations in metropolitan areas with different distributions of housing units among neighborhood types?

Hypothesis 2: Housing rent is expected to be higher in rail-oriented pedestrian-friendly neighborhoods and lower in auto-oriented neighborhoods. As a result, housing cost burden is expected to be higher in rail-oriented pedestrian-friendly neighborhoods.

Housing costs are expected to be higher in rail-oriented pedestrian-friendly neighborhoods because the benefits from transit accessibility and a pedestrian-friendly environment are separately capitalized in the housing market. However, the relationship between housing costs and neighborhood built-environment is expected to be moderated by the share of housing units in alternative neighborhoods such as other rail-oriented and pedestrian-friendly neighborhoods at the metropolitan level.

Specifically, the relationship is expected to be more pronounced in homogenous low-density metropolitan areas because of a large unmet demand for compact and walkable urban environments. On the other hand, in metropolitan areas with a heterogeneous housing supply, the supply of housing in neighborhoods that serve as alternatives to high-demand transit-rich pedestrian-friendly neighborhoods allows parsing the demand for transit from the demand for walkability or the demand for both, thus reducing the pressure on one type of neighborhood. In these areas, demand for transit-rich pedestrian-friendly urban environments has already been met and this neighborhood type will have smaller effect on housing costs.

Transportation Costs and Affordability

Question 3: How do transportation costs and affordability vary between neighborhoods with different urban environments and levels of transit-based job accessibility near and away from rail stations?

Hypothesis 3: Transportation costs are expected to be lower in rail-oriented pedestrian-friendly neighborhoods and higher in auto-oriented neighborhoods with lower levels of transit accessibility. As a result, transportation is expected to be more affordable in transit-rich neighborhoods, especially those served by rail.

Transportation costs are expected to be lower in transit-rich neighborhoods because of the ability to substitute auto ownership with transit use. On the other hand, lower-density neighborhoods, including near rail, are still auto-oriented and therefore are expected to be associated with higher transportation costs and cost burdens.

Location Affordability

Question 4: How does location affordability (combined housing and transportation affordability) vary between neighborhoods with different urban environments and levels of transit-based job accessibility near and away from rail stations in metropolitan areas with different distributions of housing units among neighborhood types?

Hypothesis 4: Building on Hypotheses 2 and 3, neighborhoods are expected to be more affordable in rail-proximate and pedestrian-friendly neighborhoods, especially within metropolitan areas with a heterogeneous housing market. While housing is expected to be less affordable in transit-rich and walkable neighborhoods, transportation is expected to be more affordable, resulting in better overall affordability.

However, neighborhood affordability might also vary between metropolitan areas. In low-density metropolitan areas, housing costs and affordability near rail stations are driven by demand for compact mixed-use development as well as by accessibility benefits. At the same time, these regions also tend to be more auto-oriented, thus providing fewer opportunities to forgo private-vehicle ownership and use. As a result, both housing and transportation costs in these metropolitan areas are expected to be higher. In more compact metropolitan areas, on the other hand, rail service is often more developed and widespread, which in turn reduces demand for locating in a specific neighborhood with rail service. In addition, accessibility benefits from rail service enable more individuals to give up their private vehicles, especially in transit-rich neighborhoods. Consequently, transportation costs in compact metropolitan areas are expected to be lower and neighborhoods are expected to be more affordable.

3.3. Research Design

This dissertation adopts a multilevel and longitudinal approach to answer the research questions. The multilevel approach allows testing the relationships between neighborhood- and metropolitan-level characteristics, and it is necessary for controlling for variations between metropolitan areas. A longitudinal approach is necessary for examining the change in housing costs and affordability over time.

The universe of the study is metropolitan areas in the United States that had intra-urban rail service in 2015. The unit of analysis is different in the longitudinal and the cross-sectional sections of the analyses. The cross-sectional analyses are based on data at the block group level, which is the smallest geographic unit for which data from all sources are consistently available. The longitudinal analyses, on the other hand, are based on data at the census tract level, which is the smallest geographic unit for which data are consistently available over time.

3.3.1. Multilevel Cross-Sectional Analysis

The conceptual framework views neighborhoods as grouped within metropolitan areas. As such, the conceptual framework identifies housing and transportation costs and affordability as functions of both neighborhood-level and metropolitan-level factors, as well as of interactions between the two levels. Therefore, when modeling costs and affordability at the neighborhood level, it is necessary to account for potential variations that stem from differences between neighborhoods as well as for differences between metropolitan areas. Failing to account for variation between metropolitan areas can lead to biased effect sizes and standard errors (Raudenbush & Bryk, 2002).

Accordingly, I adopt a multilevel approach to analyze housing and transportation costs and affordability at the neighborhood level. A multilevel regression analysis is appropriate as it allows estimating results at Level 1 (e.g., neighborhood) while accounting for variation in Level 2 (e.g., metropolitan area). In the context of this research, costs and affordability are expected to vary between neighborhoods (Level 1) as well as between metropolitan areas (Level 2). Specifically, the analysis is based on a series of multilevel regression models with metropolitan-level fixed-effects. In these models, both neighborhood- and metropolitan-level factors contribute to the intercept while only neighborhood-level factors contribute to the slope (Raudenbush & Bryk, 2002). Metropolitan random effects were also considered but these were not statistically significant. A basic multilevel fixed-effect regression model can be specified separately for Level 1 and Level 2, as follows (Raudenbush & Bryk, 2002):

Level-1 regression $$y_{ij} = \beta_{0j} + \beta_{1j}X_{ij} + e_{ij} \tag{1}$$

Level-2 regression $$\begin{aligned} \beta_{0j} &= \gamma_{00} + \gamma_{01}W_j + u_{0j} \\ \beta_{1j} &= \gamma_{10} \end{aligned} \tag{2}$$

where y_{ij} is the score on the dependent variable for observation i in group j; β_{0j} is the intercept of the dependent variable in group j, which is comprised of the grand mean of the scores on the dependent variable across all groups (γ_{00}), the mean of the scores on the dependent variable that is associated with group j (γ_{01}), a Level-2 variable (W_j), and the error term for variation between groups (u_{0j}); β_{1j} refers to the average slope in group j (γ_{10}) for the relationship between a Level-1 variable and the dependent variable; X_{ij} is the score on the dependent variable for observation i in group j; and e_{ij} is the error term for the variation between Level-1 observations.

The basic functional form of the multilevel fixed-effect model is produced by combining the two separate functions in equation (1) and equation (2)

$$y_{ij} = \beta_{0j} + \beta_{1j}W_j + \beta_{2j}X_{ij} + e_{ij} + u_{0j} \tag{3}$$

where β_{0j} is the intercept of the dependent variable in group j and β_{1j} is the contribution of the average slope of a Level-2 variable (W_j) to the intercept; and β_{2j} is the contribution of a Level-1 variable (X_{ij}) to the slope.

A major argument this research advances is that housing costs and affordability in high-demand transit-oriented development are also a function of the supply of housing in alternative neighborhoods, which either offer a pedestrian-friendly environment alongside lower levels of accessibility or high accessibility with lower levels of walkability. This argument emphasizes the importance of providing housing opportunities in a diverse set of neighborhoods to allow households to better meet their housing preferences and reduce the demand for a specific neighborhood type. Multilevel models allow testing the hypothesis that the supply of housing in alternative neighborhoods have a moderating effect on housing costs in TODs through the interaction between Level-1 and Level-2 variables (Aguinis et al., 2013; Raudenbush & Bryk, 2002). In the context of this study, such cross-level interactions estimate the moderating effect of a Level-2 variable, for example, the supply of housing in non-rail pedestrian-friendly or rail-oriented intermediate development, on the effect size associated with a Level-1 variable (e.g., neighborhood type). The functional form of a fixed-effects model with a cross-level interaction is described as follows

$$y_{ij} = \beta_{0j} + \beta_{1j}W_j + \beta_{2j}X_{ij} + \beta_{3j}W_jX_{ij} + e_{ij} + u_{0j} \tag{4}$$

where $\beta_{3j}W_jX_{ij}$ denotes the interaction between a Level-2 variable (W_j) and a Level-1variable (X_{ij}). If the Level-2 variable (W_j) has a moderating effect, each level in the Level-1variable (X_{ij}) will have a different slope.

The analysis in this study is based on a variety of multilevel regression models that are used to examine the factors that are associated with housing and transportation costs and affordability. While these models differ in their dependent variables, they mostly contain a similar set of dependent variables (Table III-1). Therefore, a single empirical model with cross-level interactions is used to describe the multiple multilevel cross-sectional models that are constructed, though most models do not include an interaction term. Using equation (4), the empirical model is

$$y_{ij} = \beta_0 + \beta_{1j}M_j + \beta_{2j}NSD_{ij} + \beta_{3j}NH_{ij} + \beta_{4j}NT_{ij} + \beta_{5j}NB_{ij} + \beta_{6j}MH_j + \beta_{7j}MH_jNB_{ij} + e_{ij} + u_{0j} \tag{5}$$

where

y_{ij}	=	dependent variable at neighborhood i in metropolitan area j;
M_j	=	vector of metropolitan characteristics;
NSD_{ij}	=	vector of neighborhood socio-demographic characteristics;
NH_{ij}	=	vector of neighborhood housing characteristics;
NT_{ij}	=	vector of neighborhood transportation characteristics;
NB_{ij}	=	a categorical variable of neighborhood types based on built-environment characteristics;
MH_j	=	vector of metropolitan housing supply characteristics or land-use regulations;
MH_jNB_{ij}	=	a cross-level interaction term between metropolitan housing supply or land-use regulations and neighborhood type;
e_{ij}	=	error term for the unexplained variation between neighborhoods;
u_{0j}	=	error term for the unexplained variation between metropolitan areas.

The different dependent variables require using different estimation approaches (Table III-2). The basic multilevel fixed-effect models are based on a maximum likelihood estimation. However, several dependent variables require adopting a fixed-effect logit estimation approach to examine whether neighborhoods are affordable to households earning 80% of their area median income. In addition, a fixed-effect Tobit approach was taken to model housing rent. This approach is necessary since the Census Bureau censors median gross rent data at the block-group level for privacy reasons. Unlike the basic maximum likelihood, Tobit models take into account that the data are censored by including in the estimation of y_{ij} the probability of being censored (Tobin, 1958).

Table III-1: List of Dependent and Independent Variables in the Cross-Sectional Analysis

Variable	Description	Analysis	Notation
Dependent Variables			
Annual Median Gross Rent (2019$)	Annual median gross rent in 2019 dollars	HC	y_{ij}
Annual Average Estimated Transportation Costs (2019$)	Annual average transport costs in 2019 dollars	TC	y_{ij}
Car Availability	The share of households with at least one private vehicle	TC	y_{ij}
Commute: Transit	Share of commute trips made by transit	TC	y_{ij}
Commute: Rail	Share of commute trips made by rail	TC	y_{ij}

Housing Cost burden	Median gross rent as a share of area median income	HA	y_{ij}
% Affordable 1-2 Bedroom Housing Units	The share of 1 and 2-bedroom housing units that rent for less than the fair market rate (FMR)	HA	y_{ij}
Neighborhood Affordable at 80% Area Median Income	Whether housing is affordable at 80% of area median income: Affordable (0) - median gross rent < 30% of moderate income; Unaffordable (1) - median gross rent > 30% moderate income	HA	y_{ij}
Transportation Cost burden	Transportation costs as a share of area median income	TA	y_{ij}
Transportation Affordable at 80% Area Median Income	Whether transportation is affordable at 80% of area median income: Affordable (0) - transportation costs < 15% of moderate income; Unaffordable (1) - transportation costs > 15% moderate income	TA	y_{ij}
Location Cost burden	Housing and transportation costs as a share of area median income	LA	y_{ij}
Neighborhood Affordable at 80% Area Median Income	Whether housing and transportation is affordable at 80% of area median income: Affordable (0) - housing and transportation costs < 45% of moderate-income; Unaffordable (1) - housing and transportation costs > 45% moderate-income	LA	y_{ij}
Neighborhood-Level Variables (Level 1)			
% Black	Share of black households	All	β_2
% Hispanic	Share of Hispanic households	All	β_2
% Age 25-39	Share of individuals aged 25-39	All	β_2
Average Household Size	The average number of members in a household	All	β_2
Median Household Income (1000s)	Median household income (2019$)	All	β_2
% Small Housing Units	Share of 1 and 2-bedroom housing units	HC, HA, LA	β_2
% Multi-family Housing Units	Share of housing units in a structure with 5 or more housing units	TC, TA	β_3
% New Development	Share of housing units built since 2000	HC, HA, LA	β_3
Median House Value (1000s)	Median house value (2019$)	HC	β_3
Distance to Highway Ramp (Km)	Street-network distance to the nearest highway ramp	All	β_4
Distance to Rail (Km)	Street-network distance to the nearest rail station	All	β_4
Distance to CBD (Km)	Euclidian distance to the central business district	All	β_4
Job Accessibility	The number of jobs accessible by transit within 45-minutes	All	β_4
Neighborhood Type	A categorical variable of six neighborhood types	All	β_4
Metropolitan-Level Variables (Level 2)			
Population	The urbanized population of a metropolitan area	HC, HA	β_1
Median House Value (1000s)	Median house value (2019$)	HC, HA, LA	β_1
Population Density	Population per acre	TC, TA	β_1
Fixed-Guideway Vehicle Revenue Miles (Millions)	Fixed-guideway vehicle revenue miles	TC, TA, LA	β_1
Wharton Index	Standardized Wharton Index, which combines the results from over 100 variables.	HC	β_6

Multi-Family Development Approval Time	A standardized measure of 1) the average length of time for re-zoning permits to be approved; 2) the average length of time for subdivision permits to be approved.	HC	β_6
Multi-Family Constraints	A standardized measure of 1) density restrictions on multi-family housing; 2) length of the zoning process for multi-family housing; 3) length of the permit process for multi-family housing.	HC	β_6
Housing Unit to Population Ratio	The ratio of housing units in a metropolitan area to the total population in the metropolitan area	HC	β_6
% TOD Housing Units	Share of housing units in transit-oriented development	HC	β_6
% Non-Rail Pedestrian-Friendly Units	Share of housing units in non-rail pedestrian-friendly development	HC, HA	β_6
% Rail-Oriented Intermediate Units	Share of housing units in rail-oriented intermediate development	HC, HA	β_6

Note: HC: Housing Cost analysis; TC: Transportation Cost analysis; HA: Housing Affordability analysis; TA: Transportation Affordability analysis; LA: Location Affordability analysis

Table III-2: Dependent Variables and Estimation Methods

Dependent Variable	Estimation Method	Comments
Annual Median Gross Rent (2019$)	Fixed-Effects Tobit	Lower limit: $1,264; Upper limit: $44,709
Annual Average Estimated Transportation Costs (2019$)	Fixed-Effects	
Car Availability	Fixed-Effects	
Commute: Transit	Fixed-Effects	
Commute: Rail	Fixed-Effects	
Housing Cost burden	Fixed-Effects	
% Affordable 1-2 Bedroom Housing Units	Fixed-Effects	
Neighborhood Affordable at 80% Area Median Income	Fixed-Effects Logit	
Transportation Cost burden	Fixed-Effects	
Transportation Affordable at 80% Area Median Income	Fixed-Effects Logit	
Location Cost burden	Fixed-Effects	
Neighborhood Affordable at 80% Area Median Income	Fixed-Effects Logit	

3.3.2. Multilevel Longitudinal Analysis

The longitudinal portions of the analysis take on a similar form to the cross-sectional portions but allow some variables to vary over time. This allows examining how housing costs and affordability change over time with changes in neighborhood built-environment characteristics. In the basic multilevel longitudinal model, time t (Level-1) is grouped by observation i (Level-2), which are further grouped by group j (Level-3). Building on equation (4), the functional form of the model is

$$y_{tij} = \beta_{0j} + \beta_{1j}W_j + \beta_{2j}t_{ij} + \beta_{3j}X_{ij} + \beta_{4j}X_{ij}t_{ij} + \beta_{5j}W_jX_{ij}t_{ij} + e_{ij} + u_{0j} \tag{6}$$

where y_{tij} is the score on the dependent variable at time t for observation i in group j; the intercept is comprised of the average score on the dependent variable in group j (β_{0j}), the contribution of the average slope from a Level-3 variable ($\beta_{1j}W_j$) and the expected outcome for a neighborhood (Level-2) at the initial time-point ($\beta_{2j}t_{ij}$); β_{4j} allows a Level-2 variable (X_{ij}) to vary over time (t_{ij}); and β_{5j} allows the cross-level interaction between a Level-3 variable (W_j) and a Level-2 variable (X_{ij}) to vary over time (t_{ij}). Equation (6) is then used to specify a general longitudinal multilevel model

$$\begin{aligned} y_{tij} = \beta_0 + \beta_{1j}M_j + \beta_{2j}NSD_{ij}t_{ij} + \beta_{3j}NH_{ij} + \beta_{4j}NT_{ij}t_{ij} + \beta_{5j}NB_{ij}t_{ij} + \beta_{6j}MH_jt_{ij} + \beta_{7j}MH_jNB_{ij}t_{ij} \\ + e_{ij} + u_{0j} \end{aligned} \tag{7}$$

where

y_{tij}	=	dependent variable at time t in neighborhood i and metropolitan area j;
M_j	=	vector of metropolitan characteristics;
$NSD_{ij}t_{ij}$	=	vector of neighborhood socio-demographic characteristics which allows factors (e.g., income) to vary over time;
NH_{ij}	=	vector of neighborhood housing characteristics;
$NT_{ij}t_{ij}$	=	vector of neighborhood transportation characteristics which allows factors to vary over time;
$NB_{ij}t_{ij}$	=	a categorical variable of neighborhood types based on built-environment characteristics;
MH_jt_{ij}	=	vector of metropolitan housing supply characteristics or land-use regulations;
$MH_jNB_{ij}t_{ij}$	=	a cross-level interaction term between metropolitan housing supply or land-use regulations and neighborhood type;
e_{ij}	=	error term for the unexplained variation between neighborhoods;
u_{0j}	=	error term for the unexplained variation between metropolitan areas.

Because of data limitations, the longitudinal analysis includes calculations on housing costs and affordability but not on transportation costs. The unit of analysis in this section is also different—census tracts rather than block groups. The estimation procedure in the longitudinal analysis is similar to the basic multilevel fixed-effect models and is based on a maximum likelihood estimation. The key difference from the cross-sectional analysis is that time (t) is introduced as the lowest level in the analysis. Interacting the time variable with other variables at the neighborhood or metropolitan allows the effect size that is associated with them to vary over time. The decision about which variables to allow to vary over time and which variables to keep constant is based on the research questions and theoretical considerations. For example, the share of small housing units in a neighborhood was not specified to vary with time since it is expected to have a similar relationship with rent at each of the time points. On the other hand, income was allowed to vary with time since it is expected that the relationship between housing consumption and income has become stronger over time.

Data were collected for five-time points: 1980, 1990. 2000, 2012 (2008-2012), and 2017 (2013-2017). The time variable is a categorical variable with the year 2000 as the reference year. The year 2000 was chosen since it is positioned in the middle of the time range and therefore provides a more meaningful discussion of the difference between years. For a categorical variable, the effect size is calculated as the difference between the relationship of each category with the dependent variable and the relationship of the reference category with the dependent variable. Hence, if 1980 was chosen as the reference year, the effect sizes associated with 2012 and 2017 would represent the difference 1980. These are large gaps in time, which make the interpretation of the results less meaningful. Using 2000 as the base year is thus preferred as it allows a more nuanced, and more conservative, analysis of change over time.

3.4. Data Collection and Preparation

The analyses in this dissertation are based on two separate datasets that correspond to the two research approaches that are employed—cross-section and longitudinal analysis—and the units of analysis that are appropriate for each approach. The cross-sectional analyses are based on data at the block group level, which is the smallest geographic unit for which data from all sources are consistently available. The longitudinal analyses, on the other hand, are based on data at the census tract level, which is the smallest geographic unit for which data are consistently available over time.

3.4.1. Metropolitan Areas and Rail Systems

Data for the cross-sectional and longitudinal datasets were collected for the urbanized areas within 27 U.S. metropolitan areas that had intra-urban light, heavy, or commuter rail service in 2015 (Table III-3). The decision to include commuter rail in the analysis stems from the fact that in some metropolitan areas, commuter rail stations attract similar development patterns to light rail stations, including in transit-oriented development. Thirty metropolitan areas with intra-urban rail service were identified. However, three of these metropolitan areas (Albuquerque, NM; Hartford, CT; and Nashville, TN) were excluded from the final sample since they only include commuter rail that provides service mostly outside of the central city in the region. Austin, TX is also served only by commuter rail, but rail stations are located in developed urbanized areas and therefore the metropolitan area was kept in the sample.

The data include 20 light rail systems, 11 heavy rail systems, and 1 commuter rail systems. Heavy rail systems tend to be older and to be located in East Coast metropolitan areas (Table III-3). Newer heavy rail systems, however, have been built since the 1970s in growing regions like

San Francisco, Los Angeles, Atlanta, and Washington DC. Light rail systems, on the other hand, tend to be younger systems, with the majority of them built or upgraded since the 1980s. In many cases, light rail systems were built in metropolitan areas that did not have a rail system before hand, often on the tracks of older freight and out-of-service commuter rail systems.

Commuter rail systems, which tend to serve more suburban and ex-urban areas, are typically characterized by larger directional route miles than heavy and light rail but lower vehicle revenue miles and unlinked passenger trips (when New York is excluded; Table III-4; Table III-5). Heavy rail systems, on the other hand, which tend to be located in larger and denser metropolitan areas, are also characterized by higher levels of vehicle revenue miles and unlinked passenger trips. The better service provided by heavy rail systems is due, in part, to their operation in denser and more populated metropolitan areas. In addition, heavy rail trains also operate on tracks that grade-separated for other vehicles, are faster, and tend to have larger capacities when compared to light rail cars.

The data were cleaned to represent the urbanized areas of each metropolitan area. Urbanized areas are a classification produced by the Census Bureau to distinguish between urban and rural areas within a metropolitan area. Since 2010, urban areas are classified as areas within a metropolitan area with 50 thousand or more people or urban clusters with at least 2,500 people. To fit the data to the urban areas of a metropolitan area, the cross-sectional block-group data were clipped using a shapefile of each metropolitan area's urban area. The data were further cleaned to exclude block groups with no land area, block groups with large land areas (Land > 6 Sq KM), block groups with no population or housing units, and block groups with low housing-unit densities (density < 0.1 units per dunam). The remaining block groups resemble in their distribution the shapefile of the urban areas in an MSA.

Table III-3: Rail Systems, Year Opened, and Number of Stations

MSA	Population (Millions)	Year Opened			Stations		
		Light Rail (N=20)	Heavy Rail (N=11)	Commuter Rail (N=17)	Light Rail	Heavy Rail	Commuter Rail
New York	18.8	1932	1925	1832	41	391	357
San Francisco	3.4		1979	1992		45	18
Washington DC	4.9		1976	1992		91	26
Chicago	8.7		1892	1856		139	245
Boston	4.3	1897	1901	1931	66	52	128
Salt Lake City	1.1	1999		2008	50		5
Philadelphia	5.5		1936	1834		72	166
Baltimore	2.3	1992	1983	1830	33	14	12
Atlanta	4.7		1979			38	
Denver	2.5	1994			43		
Portland	1.9	1986		2009	95		5
San Diego	3.1	1981		1995	67		3
St. Louis	2.2	1993			35		
Los Angeles	12.5	1990	1993	1991	66	16	56
San Jose	1.7	1987		1998	61		17
Sacramento	1.8	1987			55		
Minneapolis	2.7	2004		2009	37		7
Miami	5.8		1984	1989		22	18
Dallas	5.4	1996		1990	62		11
Cleveland	1.8	1920	1955		33	18	
Seattle	3.2	2009		2002	19		12
Pittsburgh	1.7	1902			52		
Buffalo	0.9	1985			15		
Charlotte	1.3	2004			15		
Phoenix	3.8	2008			32		
Houston	5.3	2004			37		
Austin	1.5	2010					9
Average	4.2				46	82	64

Note: Metropolitan areas in order of Total VRM per Capita.

Table III-4: Vehicle Revenue Miles and Directional Route Miles by Rail System

MSA	Vehicle Revenue Miles (VRM; Millions)			Total VRM per Capita	Directional Route Miles (DRM)			Total DRM per Capita
	Light Rail	Heavy Rail	Commuter Rail		Light Rail	Heavy Rail	Commuter Rail	
New York	2.4	361.0	200.3	30.0	46.5	546.6	2185.7	147.8
San Francisco		67.3	6.8	21.8		209.0	153.7	106.7
Washington DC	85.5		2.1	17.9		234.2	161.5	80.8
Chicago		71.3	43.4	13.2		207.8	1155.2	156.7
Boston	6.2	22.4	21.9	11.8	51.0	76.3	776.1	210.1
Salt Lake City	6.6		5.4	10.9	93.9		174.5	244.0
Philadelphia		21.4	23.5	8.2		106.4	591.3	126.9
Baltimore	3.0	5.0	6.2	6.2	57.6	29.4	400.4	211.9
Atlanta		22.2		4.7		96.1		20.4
Denver	11.1			4.4	94.2			37.7
Portland	7.8		0.2	4.2	104.3		29.2	70.3
San Diego	8.6		1.4	3.2	108.4		82.2	61.5
St. Louis	6.2			2.8	91.1			41.4
Los Angeles	13.7	7.0	13.1	2.7	136.3	31.9	777.8	75.7
San Jose	3.5		1.0	2.7	81.0			47.6
Sacramento	3.9			2.2	76.1			42.3
Minneapolis	5.1		0.5	2.1	44.3		77.9	45.2
Miami		8.3	3.5	2.0		49.8	142.2	33.1
Dallas	9.7		1.2	2.0	182.4		72.3	47.2
Cleveland	0.8	2.5		1.9	30.4	38.1		38.0
Seattle	2.7		1.8	1.4	30.8		163.8	60.8
Pittsburgh	2.1			1.3	49.6			29.2
Buffalo	0.8			0.9	12.4			13.8
Charlotte	1.0			0.8	18.6			14.3
Phoenix	2.5			0.7	39.2			10.3
Houston	2.4			0.4	41.8			7.9
Austin			0.3	0.2			64.2	42.8
Average	8.9	58.8	20.8	5.9	69.5	147.8	465.3	74.4
Excluding NY	9.2	25.3	8.8	5.0	70.7	107.9	342.4	71.6

Note: Metropolitan areas in order of Total VRM per Capita.

Table III-5: Unlinked Passenger Trips by Rail System

MSA	Unlinked Passenger Trips (Millions)			Total Unlinked Passenger Trips per Capita
	Light Rail	Heavy Rail	Commuter Rail	
New York	19.7	2756.5	276.6	162.4
San Francisco		134.7	19.0	45.2
Washington DC		270.2	4.5	56.1
Chicago		241.7	76.2	36.5
Boston	60.8	174.9	32.9	62.5
Salt Lake City	19.7		4.6	22.1
Philadelphia		110.9	39.0	27.3
Baltimore	7.7	13.9	9.3	13.4
Atlanta		72.5		15.4
Denver	25.5			10.2
Portland	37.7		0.5	20.1
San Diego	40.1		4.4	14.4
St. Louis	16.6			7.6
Los Angeles	62.8	47.5	14.0	9.9
San Jose	11.3			6.7
Sacramento	12.1			6.7
Minneapolis	23.0		0.7	8.8
Miami	0.0	21.9	4.3	4.5
Dallas	29.8		2.2	5.9
Cleveland	2.6	6.4		5.0
Seattle	11.5		3.9	4.8
Pittsburgh	8.0			4.7
Buffalo	4.4			4.9
Charlotte	5.0			3.9
Phoenix	14.3			3.8
Houston	15.3			2.9
Austin			0.8	0.6
Average	20.4	350.1	30.8	21.0
Excluding NY	20.4	109.5	14.4	15.5

Note: Metropolitan areas in order of Total VRM per Capita.

A similar process was also applied to the longitudinal data. First, census tracts in all years were identified as either within or outside of the 2010 urban area and census tracts outside the urban area were removed. The data were further cleaned to exclude census tracts with no land area, with large land areas (Land > 10 Sq KM), with no population or housing units, and with low housing-unit densities (density < 0.1 units per dunam). Finally, census tracts that appear in only one of the five time points were removed to ensure a panel-type data set which is required for a longitudinal regression analysis.

3.4.2. Variable Data Sources

Data were collected from multiple sources and joined at each unit of analysis using geographic information systems (Table III-6). Geographic boundaries for the longitudinal and cross-sectional analysis were obtained from the National Historical GIS portal (NHGIS; https://www.nhgis.org/) housed at the University of Minnesota. This portal is also the source of socio-demographic and housing-related data at the block group level. Socio-demographic and housing data for the longitudinal analysis were obtained through Social Explorer (https://www.socialexplorer.com/), which provides a wider range of longitudinal variables than NHGIS. Specifically, Social Explorer provides data from past Decennial Censuses as well as from recent American Community Surveys based on 2010 geographies. Longitudinal data on rent and income were obtained from the Brown University Longitudinal Database portal, which provides historical census data that is adapted to 2010 census tracts. All monetary values were adjusted to 2019 dollars using the Census Bureau CPI Inflation Calculator.

Rail station locations and rail routes were obtained from state, metropolitan, and municipal sources. Where these sources did not have adequate data, rail station information was obtained from TransitFeeds (http://transitfeeds.com/), which is a portal containing General Transit Feed Specification (GTFS) data on transit service uploaded by transit agencies. Other transportation data include the road network and highway ramps, which were downloaded from the Census Bureau TIGER/Line Shapefiles portal. Road-network data, however, was not available for 1980 and 1990 and was, therefore, was not used for the longitudinal analysis. Additional metropolitan-level transportation data, such as fixed-guideway vehicle revenue miles, were obtained from the National Transit Database portal.

Table III-6: Variable Descriptive Statistics, Cross-Sectional Analysis

Variable	Mean	SD	%	Data Source
Dependent Variables				
Annual Median Gross Rent (2019$)	15,963	6,360		ACS 5-year (2011-2015)
Annual Average Estimated Transportation Costs (2019$)	11,925	3,052		Center for Neighborhood Technology (CNT)
Car Availability	86.0	18.9		ACS 5-year (2011-2015)
Commute: Transit	12.8	18.3		ACS 5-year (2011-2015)
Commute: Rail	5.4	14.0		ACS 5-year (2011-2015)
Housing Cost burden	21.0	9.2		Self-Calculated based on ACS 5-year (2011-2015) and HUD
% Affordable 1-2 Bedroom Housing Units	37.4	29.4		Self-Calculated based on ACS 5-year (2011-2015) and HUD
Neighborhood Affordable at 80% Area Median Income	0.3	0.5		Self-Calculated based on ACS 5-year (2011-2015) and HUD
Transportation Cost burden	15.7	4.8		Self-Calculated based on CNT and HUD
Transportation Affordable at 80% Area Median Income	0.8	0.4		Self-Calculated based on CNT and HUD
Location Cost burden	35.9	11.9		Self-Calculated
Neighborhood Affordable at 80% Area Median Income	0.4	0.5		Self-Calculated
Neighborhood-Level Variables (Level 1)				
% Black	15.9	25.3		ACS 5-year (2011-2015)
% Hispanic	22.7	25.3		ACS 5-year (2011-2015)
% Age 25-39	21.7	10.0		ACS 5-year (2011-2015)
Average Household Size	2.8	0.7		ACS 5-year (2011-2015)
% Small Housing Units	44.0	29.0		ACS 5-year (2011-2015)
% Multi-family Housing Units	24.3	29.5		ACS 5-year (2011-2015)
% New Development	9.5	16.2		ACS 5-year (2011-2015)
Median Household Income (1000s)	78,589	43,401		ACS 5-year (2011-2015)
Median House Value (1000s)				ACS 5-year (2011-2015)
Distance to Highway Ramp (Km)	2.3	2.0		Self-Calculated
Distance to Rail (Km)	7.6	10.2		Self-Calculated
Distance to CBD (Km)	25.0	20.0		Self-Calculated
Job Accessibility	300	547		EPA Smart Location Database
Neighborhood Type				
Transit-Oriented Development			3.7	Self-Calculated
Non-Rail Pedestrian-Friendly			6.5	Self-Calculated
Rail-Oriented Intermediate			7.7	Self-Calculated
Non-Rail Intermediate			25.8	Self-Calculated
Transit-Adjacent Development			2.9	Self-Calculated

Auto-Oriented Development			57.1	Self-Calculated
Metropolitan-Level Variables (Level 2)				
Population	7,932	6,087		ACS 5-year (2011-2015)
Median House Value (1000s)	333	147		ACS 5-year (2011-2015)
Population Density	3.1	0.8		Self-Calculated based on Census Data
Fixed-Guideway Vehicle Revenue Miles (Millions)	129.1	202.2		National Transit Database
Wharton Index	0.0	1.0		Gyourko, Saiz, & Summers (2008)
Multi-Family Development Approval Time	0.3	1.0		Self-Calculatedfrom Gyourko, Saiz, & Summers (2008) based on Glaeser, Gyourko, & Saks (2006)
Multi-Family Constraints	0.2	0.9		Self-Calculated from Gyourko, Saiz, & Summers (2008)
Housing Unit to Population Ratio	0.4	0.0		Self-Calculated
% TOD Housing Units	4.5	4.3		Self-Calculated
% Non-Rail Pedestrian-Friendly Housing Units	7.2	4.9		Self-Calculated
% Rail-Oriented Intermediate Housing Units	7.8	8.4		Self-Calculated

Data for two additional variables—transit job accessibility and neighborhood walk score—were obtained from the Environmental Protection Agency's (EPA) Smart Location Mapping portal. Specifically, the Access to Jobs and Workers via Transit Tool provides a set of transit accessibility measures. The measure that is used in this study is a block-group cumulative accessibility measure of the total number of jobs that are reachable via transit or walking within a 45-minute time frame. Block group walk-scores were obtained from EPA's Smart Location Mapping Tool's National Walkability Index. This variable assigns a walk-score between 1-20 to each block group based on built-environment characteristics that are associated with the likelihood of walking as a trip mode. Built-environment factors include the degree of mixed-use development, the mix of different employment types, street-network density, and predicted commute modal split.

3.4.3. Six Neighborhood Types

The neighborhood-built environment is a central explanatory variable in studies on the effects of rail services on housing costs and location affordability. On the one hand, transportation and housing advocates and policy makers promote transit-oriented development as an approach to attract more commuters to use transit as well as to develop a more efficient urban form. At the same time, compact pedestrian-friendly neighborhoods are also associated with higher housing costs, though with lower transportation costs. A major component of the analysis in this study is therefore to estimate the relationships between neighborhood built-environment characteristics and housing and transportation costs and affordability. To this end, I identify six types of neighborhoods based on their built-environment characteristics and their proximity to a rail station.

The analysis of neighborhood types follows the classification of neighborhoods near rail stations introduced by Renne, Tolford, Hamidi, & Ewing (2016) and broadens it also to include neighborhoods away from a rail station. This allows comparing between different types of neighborhoods near a rail station as well as to similar neighborhoods that are away from a station. Previous studies have identified various neighborhood characteristics that are associated with housing and transportation costs, including the presence of a compact (dense) and pedestrian-friendly urban form (design) with mixed-use (diversity) development (Cervero & Kockelman, 1997; Chatman, 2013; Park et al., 2016; Song & Knaap, 2003). Renne et al. (2016) build on this literature and distinguish between three types of neighborhoods near rail stations based on their housing density and walkability, a measure that incorporates both the design and the diversity aspects of a neighborhood.

Similar to the approach taken by Renne et al. (2016), for the cross-sectional portion of the analysis, I distinguish between three types of neighborhoods based on their housing density and walk-score (Table III-7). This classification is applied to neighborhoods near a rail station and away from a rail station, thus producing six neighborhood types. For the housing-density criterion, I follow the densities used by Renne et al. (2016). However, the criterion for walkability used in this study is different from the one used by Renne et al. (2016) because of the different sources the walkability data come from. While the data in Renne et al. 's (2016) study ranges from 1-100, the data used in this study range from 1-20. The decision to use a walk-score of 15 as the walkability criterion is because only about 25% of block groups have a walk-score that is higher than 15. Finally, neighborhoods are classified based on their distance to a rail station. A neighborhood is considered within the catchment area of a rail station if it is within 750-meters street-network distance of a rail station or within a 200-meter buffer around a station. The 200-meter buffer is necessary in order to ensure that all block groups immediately adjacent to a station are classified as rail-oriented.

Table III-7: Neighborhood Type Classification Criteria, Cross-Sectional Analysis

	Renne et al. (2016)		Current Study	
Criterion	Low	High	Low	High
Density	<8 units per acre	>8 units per acre	<8 units per acre	>8 units per acre
Walkability	<70	>70	<15	>15

The six types of neighborhoods that are identified include (Table III-8):

- Rail-oriented block groups
  - *Transit-oriented development* (TOD): Neighborhoods with high housing-unit densities and a high walk-score near a rail station.
  - *Rail-oriented intermediate development*: Neighborhoods with either high housing-unit densities or a high walk-score near a rail station.
  - *Transit-adjacent development*: Neighborhoods with low housing-unit densities and a low walk-score near a rail station.
- Non-rail block groups

- *Non-rail pedestrian-friendly development*: Neighborhoods with high housing-unit densities and a high walk-score away from a rail station.
- *Non-rail intermediate development*: Neighborhoods with either high housing-unit densities or a high walk-score away from a rail station.
- *Auto-oriented development*: Neighborhoods with low housing-unit densities and a low walk-score away from a rail station.

Table III-8: Neighborhood Type by Metropolitan Area, Cross-Sectional Analysis

MSA		Total Block Groups	Transit-Oriented Dev.	Non-Rail Pedestrian-Friendly	Rail-Oriented Intermediate	Non-Rail Intermediate	Transit-Adjacent	Auto-Oriented
Atlanta	Count	1,869	11	20	25	143	43	1,627
	% within MSA	100	0.6	1.1	1.3	7.7	2.3	87.1
Austin	Count	714	0	18	9	146	11	530
	% within MSA	100	0.0	2.5	1.3	20.4	1.5	74.2
Baltimore	Count	1,616	34	123	49	461	56	893
	% within MSA	100	2.1	7.6	3.0	28.5	3.5	55.3
Boston	Count	2,890	277	373	265	634	144	1,197
	% within MSA	100	9.6	12.9	9.2	21.9	5.0	41.4
Buffalo	Count	800	6	48	16	236	9	485
	% within MSA	100	0.8	6.0	2.0	29.5	1.1	60.6
Charlotte	Count	865	1	2	7	4	17	834
	% within MSA	100	0.1	0.2	0.8	0.5	2.0	96.4
Chicago	Count	6,060	245	234	628	1,549	361	3,043
	% within MSA	100	4.0	3.9	10.4	25.6	6.0	50.2
Cleveland	Count	1,471	6	30	44	289	42	1,060
	% within MSA	100	0.4	2.0	3.0	19.6	2.9	72.1
Dallas	Count	3,559	7	57	61	607	63	2,764
	% within MSA	100	0.2	1.6	1.7	17.1	1.8	77.7
Denver	Count	1,597	11	56	34	433	41	1,022
	% within MSA	100	0.7	3.5	2.1	27.1	2.6	64.0
Houston	Count	2,500	2	61	38	480	13	1,906
	% within MSA	100	0.1	2.4	1.5	19.2	0.5	76.2

Los Angeles	Count	8,020	112	854	178	2,987	99	3,788
	% within MSA	100	1.4	10.6	2.2	37.2	1.2	47.2
Miami	Count	3,271	16	221	51	1,090	44	1,849
	% within MSA	100	0.5	6.8	1.6	33.3	1.3	56.5
Minneapolis	Count	1,907	13	63	43	433	19	1,336
	% within MSA	100	0.7	3.3	2.3	22.7	1.0	70.1
New York	Count	13,670	1,395	939	3,108	3,528	415	4,285
	% within MSA	100	10.2	6.9	22.7	25.8	3.0	31.3
Philadelphia	Count	3,809	208	345	335	1,085	203	1,633
	% within MSA	100	5.5	9.1	8.8	28.5	5.3	42.9
Phoenix	Count	2,434	1	2	25	168	27	2,211
	% within MSA	100	0.0	0.1	1.0	6.9	1.1	90.8
Pittsburgh	Count	1,390	10	84	26	324	41	905
	% within MSA	100	0.7	6.0	1.9	23.3	2.9	65.1
Portland	Count	1,171	22	41	98	363	32	615
	% within MSA	100	1.9	3.5	8.4	31.0	2.7	52.5
Sacramento	Count	1,168	8	12	34	241	47	826
	% within MSA	100	0.7	1.0	2.9	20.6	4.0	70.7
Salt Lake City	Count	591	4	14	37	191	28	317
	% within MSA	100	0.7	2.4	6.3	32.3	4.7	53.6
San Diego	Count	1,644	18	135	59	440	67	925
	% within MSA	100	1.1	8.2	3.6	26.8	4.1	56.3
San Francisco	Count	2,735	92	533	81	751	51	1,227
	% within MSA	100	3.4	19.5	3.0	27.5	1.9	44.9
San Jose	Count	1,042	16	5	54	152	51	764
	% within MSA	100	1.5	0.5	5.2	14.6	4.9	73.3
Seattle	Count	2,196	18	171	26	462	13	1,506
	% within MSA	100	0.8	7.8	1.2	21.0	0.6	68.6
St. Louis	Count	1,554	3	40	31	342	24	1,114
	% within MSA	100	0.2	2.6	2.0	22.0	1.5	71.7
Washington DC	Count	1,644	71	95	96	475	77	830
	% within MSA	100	4.3	5.8	5.8	28.9	4.7	50.5
Total	Count	72,187	2,659	4,714	5,573	18,634	2,112	41,193

% of Sample	100	3.7	6.5	7.7	25.8	2.9	57.1

Note: Dev.: Development.

Walk-score and road-network data for previous decades are not available. This requires using different classification criteria to distinguish between neighborhoods and calculate the distance to a rail station. Neighborhood types for the longitudinal portion of the analysis are classified based on housing-unit density. Different density specifications were evaluated in an attempt to find density levels that would produce neighborhoods with built-environment characteristics that are similar to those of the neighborhoods in the cross-sectional portion of the analysis. The density levels that were chosen (Table III-9) produce neighborhoods that bear the greatest resemblance to the neighborhoods in the cross-sectional analysis, especially between high-density rail neighborhoods and transit-oriented development. However, this classification tends to over-identify neighborhoods as high-density rail at the expense of medium-density rail and under-identify neighborhoods as low-density non-rail (Table III-10).

Table III-9: Neighborhood Type Classification Criteria, Longitudinal Analysis

Neighborhood Type	Corresponding Rail Neighborhoods in the Cross-Sectional Analysis	Criteria	
		Housing Units per Acre	Distance to Rail
High-Density Rail / Non-Rail	Transit-oriented development	≥8	750m Euclidean distance or within a 200m buffer
Medium Density Rail / Non-Rail	Rail-oriented intermediate development	<8 and ≥3	
Low Density Rail / Non-Rail	Transit-adjacent development	<3	

Table III-10: Neighborhood Type by Year, Longitudinal Analysis

	1980		1990		2000		2012		2017	
Neighborhood Type	#	%	#	%	#	%	#	%	#	%
High Density Rail	2,082	10.1	2,175	9.8	2,365	10.4	2,535	10.9	2,603	11.2
High Density Non-Rail	2,847	13.8	2,964	13.4	3,016	13.2	3,109	13.4	3,117	13.4
Medium Density Rail	768	3.7	996	4.5	1,184	5.2	1,370	5.9	1,440	6.2
Medium Density Non-Rail	5,922	28.6	6,595	29.8	7,007	30.7	7,234	31.2	7,214	31.1

Low Density Rail	592	2.9	719	3.3	906	4.0	990	4.3	1,036	4.5
Low Density Non-Rail	8,479	41.0	8,687	39.2	8,362	36.6	7,951	34.3	7,786	33.6
Total	20,690	100	22,136	100	22,840	100	23,189	100	23,196	100

3.4.4. Housing Costs

A household's housing costs may include mortgage payments or rent, home insurance, property taxes, utilities, or some combination of these factors. The analysis in this study uses rent as the measure of housing costs due to data availability and stemming from the focus on lower-income groups. Specifically, lower-income households are more likely to rent than to own a home, and housing affordability problems are more prevalent among renters, especially low-income than among homeowners. Data on median gross rent for the cross-sectional analysis are obtained from the American Community Survey 5-year estimates (2011-2015). Data on median gross rent for the longitudinal portions of the analysis are obtained from the Brown University Longitudinal Database and from Social Explorer, both of which provide historical census data that are adapted to 2010 census tracts. All monetary values were adjusted to 2019 dollars using the Census Bureau CPI Inflation Calculator.

3.4.5. Transportation Costs

Transportation-cost figures for this study are obtained from the Center for Neighborhood Technology's H+T Index (https://www.cnt.org/). The H+T Index provides a tool for calculating the affordability of block groups in the United States based on housing and transportation-cost estimates. While the housing costs for the index are obtained from the American Community Survey, transportation costs need to be estimated using multiple sources since the U.S. Census does not provide information on transportation expenditure. The Center for Neighborhood Technology's H+T Index calculates transportation costs for block groups in the United States based on data from multiple sources on the cost of auto ownership, auto use, and transit use (Center for Neighborhood Technology, 2015).

The transportation-cost measure that is used in this dissertation is calculated using two of the three transportation-costs estimates that the H+T Index provides. The Center for Neighborhood Technology provides three income-based estimates of annual transportation costs at the block group level: for a household earning the regional median income (Regional Typical Households), a household earning 80% of the regional median income (Regional Moderate Household), and a household earning the national median household income (National Typical Household; $61,828). To account for the fact that lower-income households are expected to spend less on transportation than higher-income households, I combine the transportation costs for the regional typical household with the costs for the regional moderate household based on each neighborhood's median income. Specifically, neighborhoods with median incomes at or below 80% of their area median income were assigned the transportation-costs value for the regional moderate household while neighborhoods with median incomes higher than 80% of area median income were assigned the transportation-costs value for the typical moderate household. This calculation produces a single variable for transportation costs at the block-group level based on the income characteristics of a neighborhood.

The transportation costs that the Center for Neighborhood Technology provides combine the estimated costs of auto ownership, auto use, and transit use, given a block group's socio-demographic and locational characteristics (Center for Neighborhood Technology, 2015). Therefore, the block-group transportation costs that are produced can be viewed as the expected transportation costs at a specific location given its specific auto ownership, auto use, and transit use characteristics. To calculate transportation costs, the H+T Index separately regresses the costs associated with auto ownership, use, and transit use on thirteen independent variables. The main independent variables include median household income, average household size, average commuters per household, gross household density, fraction of single-family detached housing, employment access and diversity, transit accessibility, and average transit use. Data for these independent variables come from a variety of sources, including the American Community Survey, Longitudinal Employment-Household Dynamics (LEHD) Origin-Destination Employment Statistics (LODES), and 2013 National Transit Database. The final value of transportation costs at the block-group level is obtained by multiplying the predicted result from each model by the appropriate price for each unit—auto-ownership cost, cost per mile of auto use, and cost of transit use—and then summing the three cost elements.

3.4.6. Measures of Affordability

The affordability of a specific location to a household depends on the household's income and the costs of living in that location. These location-related costs are typically broken down into three main categories: housing costs, transportation costs, and the costs of goods and services. Based on HUD's definitions of affordable housing, which is used to determine Section 8 subsidies and vouchers, housing is considered affordable if housing costs do not exceed 30% of a household's income. Similarly, the Center for Neighborhood Technology calculated that for transportation, 15% of an area median income is a reasonable cost burden (https://htaindex.cnt.org/faq/). Combined, a neighborhood may be considered affordable if housing and transportation costs do not exceed 45% of a household's income. At the level of these cost burdens, it is assumed that households will have enough income left for non-housing or transportation goods and services, such as food, education, and healthcare.

Previous studies have identified three broad approaches to examining affordability: a household-level cost-to-income ratio, a neighborhood-level cost-to-income ratio, and a residual-income approach. Each one of these approaches has its advantages and limitations. Accordingly, each approach produces somewhat different results and is appropriate for different purposes. In this study, I adopt the neighborhood-level affordability approach. This sub-section begins, however, with a brief description of the three approaches, and then continues with a more detailed description of the neighborhood-level affordability measures that are used in this study.

Household-Level Affordability

The household-level cost-to-income ratio measures cost burden as the share of a household's income that is spent on a cost element, e.g., housing or transportation:

$$\text{Household Affordability} = \frac{\text{Household Costs}}{\text{Household Income}}$$

The benefit of this approach is that it is a direct measure of affordability, which allows identifying whether a specific household is cost burdened: if a household spends more than 30% of its income on housing, for example, is considered as housing cost burdened. However, this measure also has several disadvantages. First, it does not allow identifying whether a household is cost burdened because it is facing high housing costs or because it has a low income. Similarly, when the measure is applied broadly and uncritically, it fails to distinguish between lower-income households and higher-income households that might choose to spend more on housing and transportation in order to better meet their housing preferences or access non-housing services. In addition, household-level costs and income represent transitory income and current, perhaps temporary, housing and transportation decisions. As such, the costs and income that are used to calculate the ratio do not necessarily represents persistent low-income or housing stress.

Hence, this measure seems to be appropriate as a policy tool for evaluating the level of assistance that a specific lower-income household might require. Similarly, in research, this measure can be appropriate when discussing the situation of a specific household. The problems associated with this measure arise when households are aggregated to provide average cost burdens, for example in different neighborhoods or neighborhood types. To properly aggregate household-level information in this context requires, to the least, distinguishing between higher- and lower-income groups and higher- and lower-cost neighborhoods. Otherwise, it is difficult to identify the reasons for the cost burdens that are obtained; a low average cost burden, for example, may be a result of low costs but it might also stem from high incomes. More information about the population and the neighborhood is needed in order to interpret household-level affordability that is aggregated to neighborhood or metropolitan levels.

Residual Income (Shelter Poverty)

A second notable household-level measure of affordability is the residual income approach, often also referred to as the shelter poverty approach (Kutty, 2005; Stone, 2006; Stone, 2010). According to this measure, the amount of income (residual income) a household has available for housing (and transportation) is a product of its disposable income and the cost of obtaining a minimum standard of necessary non-housing goods and services, which varies by household characteristics (e.g., household size). Hence, housing (and transportation) costs are considered affordable if they do not exceed the household’s residual income, meaning the amount of income that the household of a given size is expected have left over after accounting for non-housing (and transportation) goods. Using the same logic, a household is considered as shelter-poor, or cost burdened, if its housing (and transportation) costs exceed the amount of income that would enable the household to pay for non-locational goods:

$$\text{Household Affordability} = \text{Locational Costs} \leq \text{Residual Income}$$

$$\text{where} \quad \text{Residual Income} = \text{Household Income} - \text{Non-Locational Costs}$$

The difference between the residual-income approach and the cost-to-income approach is that the former uses a predefined level of non-locational costs rather than assuming an arbitrary cost-burden threshold. As such, the residual-income approach has several benefits over the cost-to-income approach. First, it takes into account that a household may be cost burdened even it spends less than 30% of its income on housing or 45% of its income on housing and transportation. In addition, the measure also recognizes that different households have different needs and adjusts its calculation accordingly by setting the costs that are associated with different minimum standards of necessary non-housing goods and services. Accordingly, cost burden under the residual-income approach is a product of unaffordable locational costs rather than low incomes (Kutty, 2005).

However, the residual-income approach also has some limitations. First, like the cost-to-income approach, as a household-level measure, the residual-income approach is based on transitory income rather than permanent income. In addition, the minimal standard for non-locational costs is difficult to calculate, especially for multiple regions. The appropriate uses of the residual-income approach are, therefore, similar to those of the cost-to-income measure. In policy, the approach seems relevant for evaluating the cost burdens of specific households and distributing assistance accordingly. In research, this measure is appropriate for discussion the cost burdens of specific households. On the other hand, the measure loses too much information when figures are aggregated to neighborhood or metropolitan scales.

Neighborhood-Level Affordability

The neighborhood-level affordability measure has a similar form to the household-level ratio measure but uses neighborhood-level costs to determine whether a neighborhood is considered affordable to a household earning a specific metropolitan-wide income level (e.g., area median income):

$$\text{Neighborhood Affordability} = \frac{\text{Neighborhood} - \text{Level Costs}}{\text{Metropolitan} - \text{Level Income}}$$

The benefit of this approach is that it uses a common denominator for the calculation of cost burdens across all neighborhoods in the same region. As a result, variations in affordability between neighborhoods are only a product of the costs in each neighborhood, while income remains constant; housing in a neighborhood is considered as unaffordable if its costs account for 30% or more of area median income, for example. Moreover, using neighborhood-level costs and metropolitan-level income treats these figures as the permanent long-term conditions a household is facing. A measure of permanent income, such as a specific income-level threshold, may be a more adequate measure than the household-level approach since it reflects a household's long-term affordability abilities (Bogdon & Can, 1997; Saberi et al., 2017).

In essence, the neighborhood affordability approach allows asking whether a neighborhood is affordable to a household earning a specific income level. Accordingly, it is adequate as a policy tool for identifying potential location-efficient neighborhoods to which affordable housing efforts and lower-income households can be directed. Research-wise, this approach allows examining the affordability of neighborhoods at different income levels, with an emphasis on lower-income levels. Such an analysis allows examining the affordability of neighborhoods to households in different income groups (Bogdon & Can, 1997; Saberi et al., 2017).

3.4.6.1. Operationalizing Affordability

In this dissertation, I adopt affordability measures that are based on the neighborhood-level approach to examine housing, transportation, and affordability. These measures use neighborhood-level costs and metropolitan-wide income levels to examine cost burdens for different income levels. Specifically, three measures are employed:

Neighborhood-Level Cost burden. This measure is similar to the traditional cost-to-income ratio but uses costs at the neighborhood level and income at the metropolitan level to evaluate affordability. Hence, this approach calculates the expected cost burden associated with a neighborhood to a household earning a predefined level of income. Accordingly, the approach allows asking whether a neighborhood is affordable to a household based on its income level (Bogdon & Can, 1997; Saberi et al., 2017).

Neighborhoods Affordable at 80% of Area Median Income. This is a binary measure that allows modeling how different factors increase or decrease the odds of a neighborhood being unaffordable to a household earning 80% of the area median income. The measure calculates cost burden in a similar way to the Neighborhood-Level Cost-Burden measure.

Affordable Housing Stock. This is a measure of the share of 1- and 2-bedroom housing units in a block group that rent for less than the fair market rent. This measures the supply of small housing units that HUD considers affordable to households that receive housing assistance (Bogdon & Can, 1997).

In addition to the three measures of affordability, this study distinguishes between four income levels to examine the expected cost burden for higher- and lower-income households. Similar to HUD's classification of households by income, cost burdens are evaluated for four income levels that are derived from the area median income:

- Median-income: Income at the level of the area median income;
- Low-income: Income at 80% of the area median income;
- Very low-income: Income at 50% of the area median income
- Extremely low-income: Income at 30% of the area median income.

Cost burden is calculated relative to metropolitan income levels that are relative to a metropolitan area's median income. Information on each metropolitan area's area median income for the cross-sectional analysis is obtained from the Department of Housing and Development's Office of Policy Development and Research[2]. Area median income for the cross-sectional analysis is based on HUD Area Median Family Income for metropolitan areas in 2015. HUD calculates the HUD Area Median Family Income (HAMFI) for each jurisdiction in the United States to determine Fair Market Rents and income limits for HUD programs. The earliest date for which HUD Area Median Family Income is available is 1990. Therefore, HAMFI cannot be used for the longitudinal analysis. Instead, regional median income for the longitudinal analysis is based on metropolitan median income, as reported by the Census Bureau.

The affordable housing-stock measure reports on the share of 1- and 2-bedroom housing units in a block group that rent for less than the fair market rent. HUD calculates fair market rents (FMRs) for metropolitan areas to determine the level of rent-assistance while taking into account

[2] Source: https://www.huduser.gov/portal/datasets/il.html#null.

variation in housing costs according to the size of a house and rental markets that vary between metropolitan areas. HUD reports fair market rents for five house sizes, from efficiency apartments through 4-bedroom homes[3]. Data for 1980 are not available, so this affordability measure is used only in the cross-sectional analysis. Fair market rents were compared to census data to identify the number of 1- and 2- bedroom in each block group with rents that are close to or below FMR. FMRs in each metropolitan area typically do not precisely fit the categories in census tables that report on housing costs by housing units with different numbers of bedrooms. Therefore, an effort was made to count the number of affordable housing units by comparing, as closely as possible, the census-table categories to the fair market rent levels in each metropolitan area.

3.5. Limitations of the Research

The available data that is used in this research poses several limitations on the scope of the analysis and the interpretation of the results regarding housing and transportation costs and affordability.

Housing Quality. The census only provides limited information on housing size (i.e., number of bedrooms) and does not include information on housing quality. These are important factors that can explain housing costs, as larger and better-quality homes tend to be more expensive. Failing to account for housing quality is especially important for evaluating housing affordability for lower-income households. In some cases, especially among very low-income levels, housing that is considered affordable might be of sub-standard quality. Hence, lower-income households that are not cost burdened might still be considered as having an affordability problem if they occupy sub-standard housing and cannot afford adequate-quality housing. Consequently, identifying neighborhoods that are affordable to very low-income households

[3] Source: https://www.huduser.gov/portal/datasets/fmr.html#2015.

should be done with caution, as some of these neighborhoods might be affordable housing might not be adequate.

Transportation Costs. Data sources reporting on actual transportation costs are limited, especially for an analysis of multiple metropolitan areas. The analyses of transportation costs and affordability are based on data from the Center for Neighborhood Technology (CNT). Since these data are only estimates of expected transportation costs at the block group level, the analysis using transportation costs is limited and is based mainly on descriptive statistics. Smart and Klein (2017) compared the estimated transportation costs data from the Center for Neighborhood Technology and self-reported household transportation costs obtained from the Panel Study for Income Dynamics (PSID). The comparison reveals that the PSID self-reported household-level transportation costs data exhibit more variation than the CNT estimates. Notably, while the CNT data showed moderate associations with neighborhood compactness, transit service, walk-score, and population density, the PSID data were not correlated with these measures. This comparison suggests that caution is needed when interpreting the results of the transportation-cost analyses. Specifically, the CNT transportation-cost estimates might represent potential transportation costs, while actual costs are a factor of household- and individual-level decisions.

Longitudinal Analysis. Longitudinal data on transportation costs and other neighborhood and metropolitan characteristics such as transit job accessibility, walk-scores, road networks, fair market rents, and land-use regulations are not available. The unavailability of walk-score data limits the ability to examine housing costs as a factor of neighborhood built-environment characteristics and prevents the analysis of transportation costs over time. Similarly, the unavailability of transit job accessibility data limits the ability to fully identify the contribution of transit service to housing costs and to distinguish between this and the contribution of neighborhood built environment to housing costs. While efforts are made to overcome these limitations, the longitudinal analysis is nonetheless constrained in its ability to fully follow the cross-sectional analysis in its scope and depth.

Spatial Autocorrelation. The use of block groups as the unit of analysis in the cross-sectional sections raises the concern for spatial autocorrelation. The concern, in this respect, is that adjacent observations are not interdependent of each other since close-by block groups likely share similar socio-demographic, housing-unit, transportation, and built-environment characteristics. As a result, when spatial autocorrelation is not treated, the regression coefficients are unbiased but inefficient while the standard errors are biased. While the analyses in this dissertation do not comprehensively correct for spatial autocorrelation, they do partly control for it by accounting for neighborhood-level factors that vary by block group. These include neighborhood socio-demographic, housing, transportation, and built-environment characteristics. Incorporating these factors in the regression models helps minimize the risk of biased outcomes that spatial autocorrelation might introduce (Basu & Thibodeau, 1998; Li & Brown, 1980).

Metropolitan Random Effects. Multi-level regression models are a powerful approach that controls for the possibility that variations between observations are not only a factor of the specific characteristics of the observation but also of a factor of the group within which observations are clustered (e.g., metropolitan areas). Within this framework, another powerful tool that multi-level models enable is introducing random effects, which allow the effect that is associated with a key explanatory variable to vary between clusters. In other words, by introducing a random effect into the model, each cluster in the model has a different slope. Several attempts were conducted to introduce random effects into the regression models to allow the effect that is associated with transit job accessibility or distance from a rail station to vary by metropolitan area. However, these random-effect variables were not statistically significant and were therefore not used in the final models in the study.

Neighborhood-Level Affordability. Neighborhood-level affordability calculates cost burden relative to metropolitan-based income levels. Hence, inference regarding affordability is appropriate for a household already within a metropolitan area. Consequently, the measure might fail to identify affordability problems for potential populations that are excluded from a region due to high housing costs, for example. This limitation is partially overcome by the analysis of affordability for different income levels. In the high-cost regions, 80% and even 50% of area median income are often similar to the area median income in middle- and lower-income MSAs. Therefore, to consider whether a metropolitan area is affordable to the wider U.S. population, it might be more appropriate to compare affordability to the area median household in lower-income MSAs to affordability to moderate- or low-income levels in high-income MSAs. Such an analysis will show that higher-income MSAs, which are associated with higher housing and transportation costs, are less affordable than middle- and low-income households.

CHAPTER IV

IV. Results

4.1. Characterizing Neighborhoods and Rail-Station Areas

This research examines how proximity to rail stations, in combination with neighborhood built-environment characteristics, is associated with housing and transportation costs and affordability. Alongside these factors, a major argument this research tests is that housing in high-demand neighborhoods like transit-oriented development are expensive, in part, due to the scarcity of these and alternative neighborhoods regionwide. If this is the case, then focusing efforts on increasing housing supply only in TODs might not be enough to reduce housing costs by meeting current and future demands. To examine this, cross-sectional and longitudinal data is collected for neighborhoods in 27 U.S. metropolitan areas with heavy, commuter, or light rail systems.

Costs and affordability vary between metropolitan areas, among other things, based on their unique housing, labor, and transportation characteristics. Similarly, costs and affordability vary between neighborhoods based on their housing and transportation characteristics, the amenities they provide, and how these factors are valued and demanded by the public. By distinguishing between neighborhoods based on their built environments near and away from rail stations, the study aims to parse out the separate effects of three housing supply-side factors that might affect housing costs: proximity to rail as a demanded housing benefit; a pedestrian-friendly built environment as a demanded housing benefit; and the supply of housing in neighborhoods that serve as alternatives to high-demand transit-oriented development as a way to meet the demand for such neighborhoods.

To capture the variation in costs and affordability between neighborhoods, the research identifies six types of neighborhoods based on their housing unit density, walkability, and proximity to a rail station. This section provides descriptive statistics on the housing, transportation, and socio-demographic characteristics of the six types of neighborhoods to identify their unique characteristics. The six types of neighborhoods are:

- Rail-oriented block groups: Neighborhoods that are within walking distance of a rail station, i.e., within 750 meters street-network distance from a rail station or within a 200-meter buffer around a station.
    - *Transit-oriented development* (TOD): Pedestrian-friendly neighborhoods as a result of a dense (8 or more housing units per acre) and walkable (Walk Index>=15) built environment. Housing costs in these neighborhoods are expected to be higher than average due to the benefits from proximity to rail, high walkability, and the relative scarcity of these neighborhoods alongside high demand for them.
    - *Rail-oriented intermediate development*: Neighborhoods with a moderate level pedestrian-friendly built environment due to either high density (8 or more units per acre) or high walkability (Walk Index>=15) but not both. Housing costs might be positively affected by the benefits from proximity to rail but negatively affected by a less pedestrian-friendly environment. The supply of housing in these neighborhoods in a metropolitan area is expected to moderate the price-increase associated with TODs.
    - *Transit-adjacent development*: Auto-oriented neighborhoods characterized by low-density housing development (fewer than eight units per acre) and low levels of

walkability (Walk Index<15). These neighborhoods tend to be more suburban locations where housing costs might be negatively affected by proximity to rail but are positively affected by the larger size of homes.

- Non-rail block groups: Neighborhoods that are outside the walking distance of a rail station, i.e., more than 750 meters street-network distance from a rail station or outside of a 200-meter buffer of a station.
  - *Non-rail pedestrian-friendly development*: Pedestrian-friendly neighborhoods as a result of a dense and walkable built environment. This is the non-rail counterpart to the transit-oriented development neighborhood type. The supply of housing in these neighborhoods in a metropolitan area is expected to moderate the price-increase associated with TODs.
  - *Non-rail intermediate development*: Neighborhoods with a moderate level of a pedestrian-friendly built environment due to either high density or high walkability. This is the non-rail counterpart to the rail-oriented intermediate development neighborhood type.
  - *Auto-oriented development*: Auto-oriented neighborhoods are bedroom suburbs that are characterized by low density and low walkability. This is the non-rail counterpart to the transit-adjacent development neighborhood type.

The greatest diversity of neighborhood types is found in legacy-rail MSAs like New York, Boston, Philadelphia, and Chicago (Figure IV-1). These MSAs, which have the oldest and most expansive rail systems in the US, have historically developed around transit service, resulting in higher densities and levels of walkability both near and away from transit. Still, non-rail auto-oriented development is the most common neighborhood type, accounting for more than half of all neighborhoods in twenty-two of the twenty-seven MSAs in this research. Other MSAs with relatively expansive rail systems like San Francisco, Los Angeles, Washington DC, and Portland also have higher shares of non-rail pedestrian-friendly and intermediate neighborhoods. On the other hand, these regions also have a lower share of rail-proximate block groups, perhaps due to their smaller rail systems. At the other end of the scale are auto-oriented MSAs that are dominated by low-density single-family housing. The neighborhoods that develop around rail stations in these MSAs tend to be rail-oriented intermediate development, which typically has higher densities and walkability than transit-adjacent development but lower than TODs.

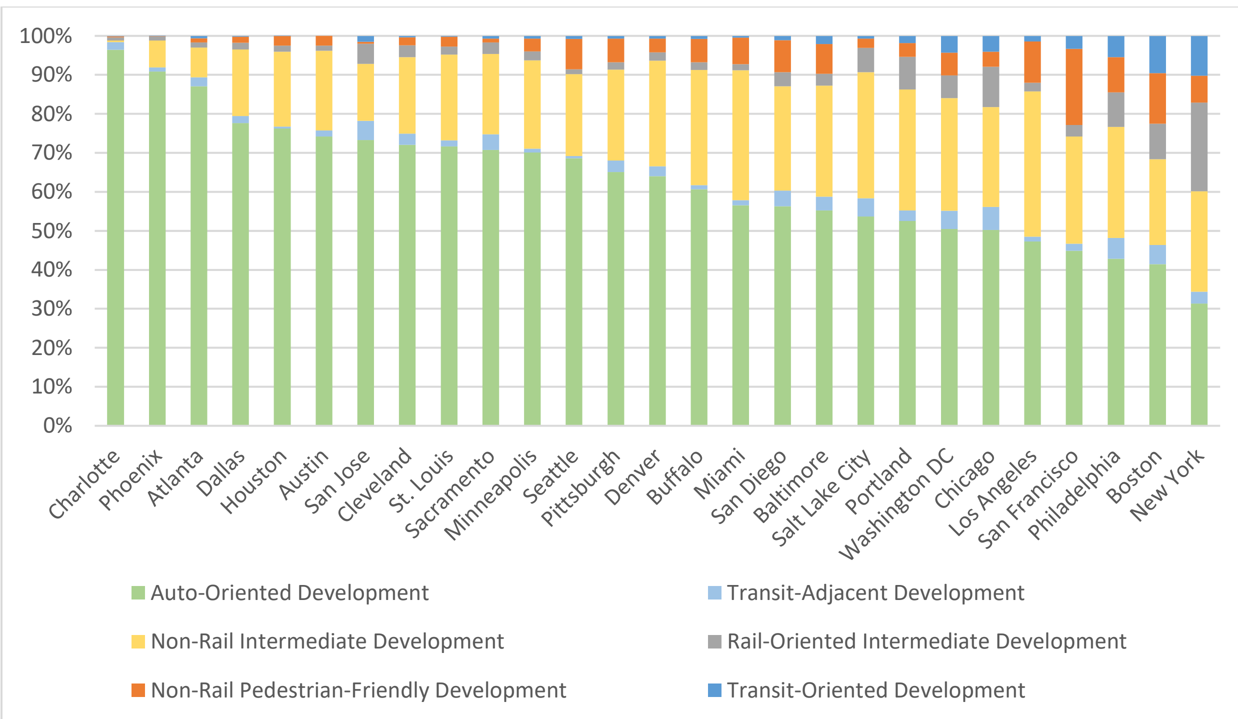

Figure IV-1: Share of Block Groups in an MSA by Neighborhood Type, All Studied Metropolitan Areas

The six neighborhood types also vary in their distribution within an MSA, with pedestrian-friendly neighborhoods occupying more central locations and auto-oriented neighborhoods more suburban locations (Figure IV-2). To provide a spatial context to the analysis, the presentation of the results is accompanied by a comparison between four metropolitan areas with different urban and rail histories, which have led to the formation of different urban forms: Atlanta, Boston, Los Angeles, and Portland. Mapping the neighborhood types in these four MSAs suggests that MSAs that have historically developed around rail (and streetcar) services, like Boston and Los Angeles, also have a greater diversity of neighborhood types, including TODs.

Boston is an industrial turned post-industrial metropolitan area. The region's rail system is comprised of light, heavy, and commuter rail routes that date back to the 19th century. The growth of the MSA alongside its rail services is evident in its urban form, which consists of a large concentration of TOD and rail-oriented intermediate neighborhoods in the central areas of the MSA and non-rail pedestrian-friendly development and non-rail intermediate neighborhoods in the inner suburban rings. Outside of the main urban core, however, the region is dominated by auto-oriented development, with mostly rail-oriented intermediate and transit-adjacent development near rail stations.

Atlanta and Los Angeles represent the archetypical auto-oriented U.S. metropolitan areas, despite both having an extensive streetcar system in place until the late 1940s and 1960s, respectively. Nevertheless, the two MSAs exhibit very different urban forms. Atlanta experienced rapid population growth since the 1940s and 1950s, after the area's streetcar system had been replaced by bus service and highways. In 1979 a new heavy rail system (MARTA) was constructed to accommodate the growth of the region. As a result, while the central city is characterized by some TOD, rail-oriented intermediate development, non-rail pedestrian-friendly development, and non-rail intermediate development near MARTA stations, the majority of the MSA is characterized by single-family auto-oriented development.

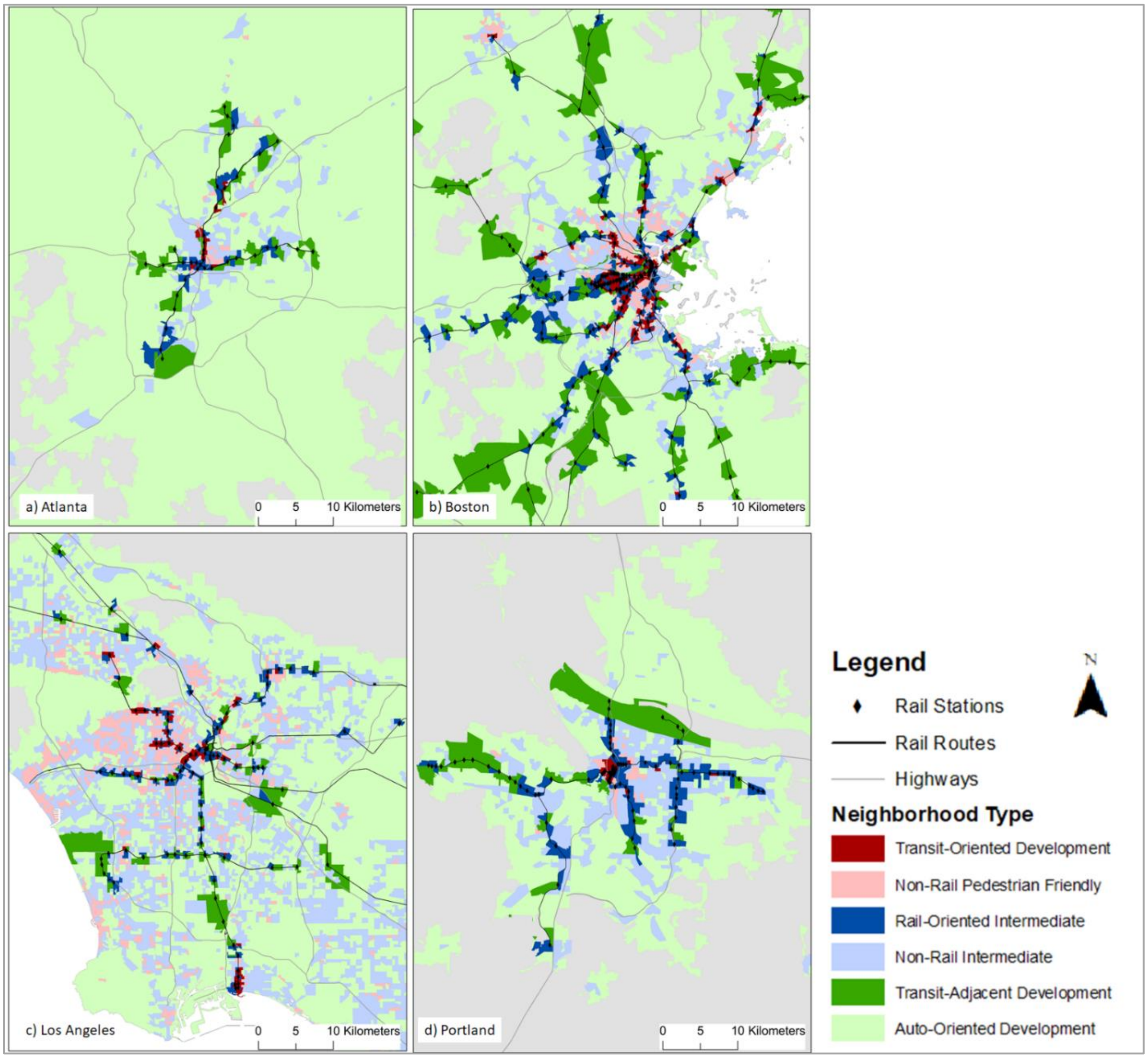

Figure IV-2: Neighborhood Types: Atlanta, Boston, Los Angeles, Portland

Los Angeles, on the other hand, has experienced rapid population growth since the early 20th century. Hence, for nearly 70 years, the region developed around an extensive streetcar network. The result is dense, single- and multi-family development in the central areas of the metropolitan region as well as outside of the urban core. Moreover, similar development patterns also extend outward, into the San Fernando Valley to the North-East and toward Orange County in the South. In 1990, the region opened its new rail system (Metro), which includes both light and heavy rail routes. The result of this urban history is a series of TOD and rail-oriented intermediate development near rail stations as well as a large share of non-rail pedestrian-friendly development and non-rail intermediate development, especially in the central parts of the region.

Finally, Portland (Oregon) is the smallest MSA among the four but has experienced fast population growth in recent decades. Similar to the other MSAs, the city also had a streetcar system dating back to the 19th century, which was finally shut down in the late 1950s. In the 1980s, Portland was among the first MSAs in the United States to develop a modern light rail system (MAX), with the first line opening in 1986. Today, the MSA is served by light and commuter rail as well as a modern streetcar network in downtown Portland. This transportation history, as well as the MSA's urban growth boundary, has contributed to relatively dense development of TOD and rail-oriented intermediate development in the central areas of the region and extending along the light and commuter rail lines to the south and east. Away from rail stations, however, the central city is characterized by non-rail intermediate development and a small share of non-rail pedestrian-friendly development, while the outer suburban rings are dominated by auto-oriented development.

Table IV-1: Built-Environment Characteristics by Neighborhood Type, All Studied Metropolitan Areas

Neighborhood Type	% of Total Block Groups	Pop.	Distance to CBD (KM)	Transit Job Accessibility	Housing Units per Acre	Walk Index	% Small Units	% New Units	% Single-Family Units
Transit-oriented	3.6%	1,428	9.0	1,374,969	36.5	16.8	74.9	10.3	7.1
Non-rail pedestrian-friendly	6.3%	1,442	12.7	474,768	16.9	16.6	68.6	7.8	18.0
Rail-oriented intermediate	7.6%	1,343	14.0	1,146,425	33.6	13.9	65.7	7.7	19.7
Non-rail intermediate	25.0%	1,409	19.9	288,639	10.6	14.4	53.6	6.3	41.0
Transit-adjacent	2.8%	1,403	23.7	235,843	3.2	12.3	42.2	9.4	55.5
Auto-oriented	54.7%	1,557	31.4	71,844	3.0	10.2	31.8	11.4	70.1

Note: Total block groups: 72,185; Pop.: Population; Data on Transit Job Accessibility is based on 23 metropolitan areas; the data for four MSAs in not available.

The built-environment characteristics and levels of accessibility of the six neighborhood types seem to follow two axes: proximity to rail and distance to the CBD (Figure IV-3; Table IV-1). Specifically, neighborhoods that are closer to the CBD and a rail station tend to have higher levels of accessibility and to be more pedestrian-friendly. On the other hand, neighborhoods away from rail and the CBD tend to be more oriented toward the private vehicle. Overall, transit-oriented development, which scores high on accessibility, density, and walkability, is characterized by a large share of small housing units and a low share of single-family housing. Moreover, TODs have also experienced relatively high shares of new housing development between 2000 and 2015, suggesting that these neighborhoods are growing at a faster rate than other neighborhood types. While TOD's non-rail counterpart—non-rail pedestrian-friendly development—also scores high on walkability, it is characterized by much lower (though still relatively high) levels of accessibility and density, which stem from lower shares of small housing units and a higher share of single-family housing.

On the other end of the CBD-distance axis are transit-adjacent development and auto-oriented development, which are auto-oriented suburban neighborhoods. These neighborhoods are characterized by low levels of accessibility, low densities, and relatively low levels of walkability. Nonetheless, transit-adjacent neighborhoods are characterized by higher shares of small housing units and lower shares of single-family housing than their non-rail counterparts. This suggests that in auto-oriented neighborhoods, proximity to rail might affect the combination of housing types that are provided, but this does not necessarily translate into denser or more pedestrian-friendly environments.

In between the pedestrian-friendly and auto-oriented neighborhoods are the rail- and non-rail intermediate neighborhoods, which score similarly on walkability but vary in their accessibility levels and housing-type composition. Rail-oriented intermediate neighborhoods are characterized by very high densities stemming from relatively high levels of accessibility, high shares of small housing units, and low shares of single-family housing. Non-rail intermediate neighborhoods, on the other hand, are characterized by much lower densities as a result of lower levels of accessibility and a smaller share of small housing units and a higher share of single-family housing. These statistics suggest that in neighborhoods just outside of the urban core, proximity to rail stations attracts denser housing development, but this may not be accompanied by more mixed-use development that would result in higher walk-scores.

The six neighborhood types also vary in their socio-demographic compositions (Table IV-2), though these differences seem to be associated with distance from the CBD rather than to proximity to a rail station. Overall, neighborhoods that are farther from the CBD (i.e., moving down in the table from transit-oriented development to auto-oriented development) tend to be categorized by older, white, higher-income, and owner-occupied households. These descriptive statistics suggest that there is some degree of residential sorting based on specific neighborhood types and distance from the CBD.

Annual median gross rent seems to vary with income, with higher rents found in higher-income neighborhoods. TODs, however, have the highest average rent but only the third-highest average income. At the same time, non-rail intermediate neighborhoods are characterized by low average rent relative to their average income level. This suggests that the combination of the medium levels of density and walkability in these neighborhoods, as well as an older housing stock, are valued less in locations that are farther from the CBD and away from rail.

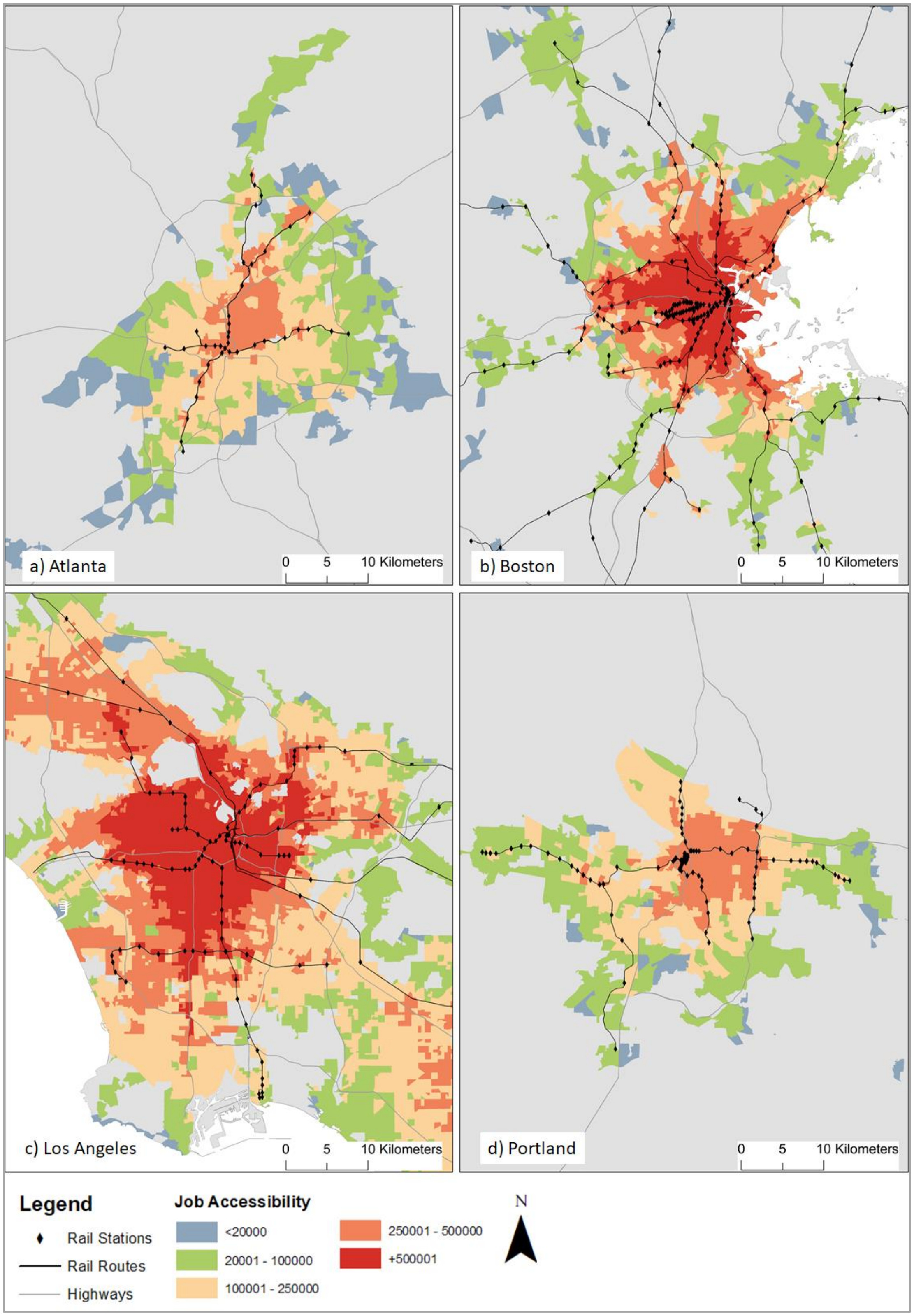

Figure IV-3: Neighborhood Transit Accessibility in Atlanta, Boston, Los Angeles, and Portland

Table IV-2: Socio-Demographic Characteristics by Neighborhood Type, All Studied Metropolitan Areas

Neighborhood Type	Annual Median Gross Rent (2019$)	Median Household Income (2019$)	% Age 25-39	Average Household Size	% White	% Black or Hispanic	% with B.A. or Higher	% Renters
Transit-oriented	17,513	72,562	30.8	2.4	42.8	40.4	45.3	71.5
Non-rail pedestrian-friendly	15,773	64,370	29.0	2.5	41.3	43.9	38.2	66.1
Rail-oriented intermediate	15,819	66,317	25.6	2.6	38.7	49.4	36.1	65.9
Non-rail intermediate	15,208	68,260	23.1	2.8	41.8	46.3	31.9	50.6
Transit-adjacent	15,736	86,741	20.5	2.8	51.9	38.3	38.0	39.5
Auto-oriented	16,311	86,493	19.2	2.9	56.7	32.9	35.1	30.2

Alongside the six neighborhood types, built-environment and socio-demographic characteristics also vary between neighborhoods based on their proximity to different rail modes. Distinguishing between heavy, light, and commuter rail, might be important since each mode provides different types and levels of service; while the stations of heavy and light rail tend to be located, on average, relatively close to the CBD, neighborhoods around heavy rail stations tend to have much higher transit job accessibility than neighborhoods around light or commuter rail stations (Table IV-3).

As a result, the neighborhoods that develop around the stations that are located closer to the CBD and that provide higher levels of service tend to be denser and more walkable (Figure IV-4). Most notable, the neighborhoods around heavy rail stations tend to be transit-oriented development and rail-oriented intermediate development (Figure IV-4). These neighborhoods are also characterized by a high share of small housing units and a low share of single-family housing, thus leading to very high housing-unit densities (Table IV-3). These characteristics most likely stem from the high levels of service heavy rail provides and the long-lasting presence of heavy rail in MSAs like New York, Boston, and Chicago, and more recently in San Francisco and Washington DC.

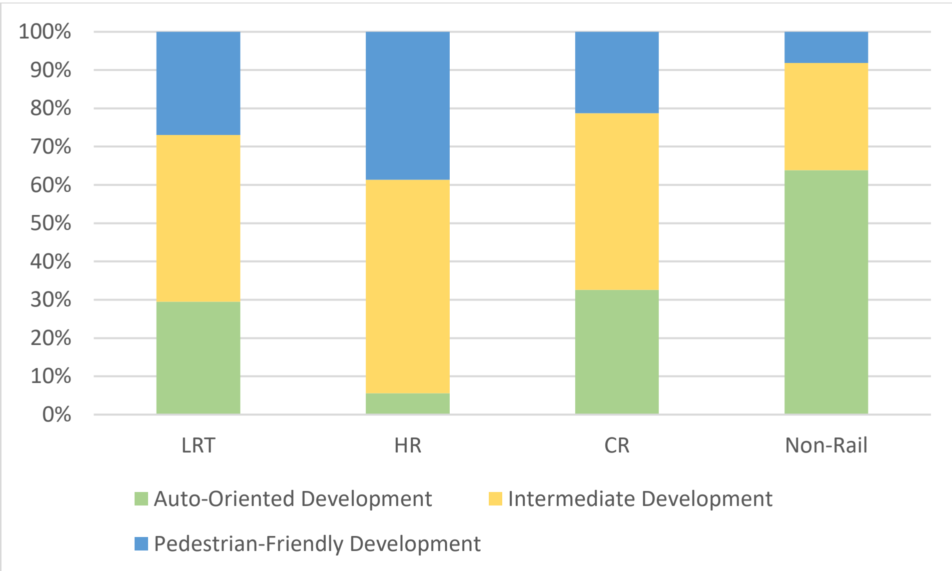

Figure IV-4: Share of Housing Units by Neighborhood Type and Mode, All Studied Metropolitan Areas

Table IV-3: Neighborhood Built-Environment Characteristics by Mode, All Studied Metropolitan Areas

Mode	% of Block Groups (n=72,803)	Distance to CBD (KM)	Transit Job Accessibility*	Housing Units per Acre	% Small Housing Units	% Single-Family Units	% New Units
Non-Rail	85.3	26.7	171,254	6.2	40.8	57.8	9.6
Commuter Rail	4.5	25.1	474,317	11.2	51.8	39.5	8.7
Light Rail	2.4	9.9	447,812	9.6	63.8	35.9	13.1
Heavy Rail	7.8	9.4	1,537,718	44.3	71.6	8.9	8.0

Note: Data on Transit Job Accessibility is based on 23 metropolitan areas; the data for four MSAs in not available.

At the same time, the lower levels of service that commuter and light rail provide relative to heavy rail, and the different types of services they provided, have led to a more equal distribution of neighborhood types around these modes' stations (Figure IV-4). Specifically, commuter rail tends to provide service that extends farther out from the CBD than light and heavy rail service (Table IV-3), which has led to higher shares of housing units in rail-oriented intermediate and transit-adjacent development. Light rail station areas, on the other hand, include more housing in transit-oriented development and rail-oriented intermediate development when compared with commuter rail station areas, but these neighborhoods also tend to be less dense than commuter rail neighborhoods despite having a higher share of small housing units and a lower share of single-family housing. These seemingly contradictory statistics might stem from many light rail systems being built on old commuter or freight railways that are located along less populated and lower-income corridors. Nonetheless, light rail neighborhoods have experienced the fastest growth in new housing units since 2000, suggesting that these neighborhoods are changing fast, perhaps into denser built environments.

Table IV-4: Neighborhood Socio-Demographic Characteristics by Mode, All Studied Metropolitan Areas

Mode	Annual Median Gross Rent	Median Household Income	% Age 25-39	Average Household Size	% White	% Black or Hispanic	% with B.A. or Higher	% Renters
Non-Rail	15,907	79,622	21.0	2.8	51.2	37.6	34.4	38.8
Commuter Rail	16,162	82,087	22.2	2.6	50.7	39.0	39.8	48.4
Light Rail	14,800	64,408	27.4	2.5	45.8	41.0	37.8	61.2
Heavy Rail	16,903	68,353	28.2	2.6	36.2	49.5	39.5	71.5

Neighborhoods built around rail stations tend to exhibit unique socio-demographic compositions (Table IV-4) stemming from the interaction between transit level of service, location within the MSA, and built-environment characteristics. On the one hand, perhaps due to their suburban location, neighborhoods near commuter rail stations tend to resemble non-rail neighborhoods in terms of annual median gross rent, as well as median household income, and their racial and ethnic composition. On the other hand, heavy rail neighborhoods, which tend to be located closer to the CBD and in older metropolitan areas, are characterized by higher house rents but lower incomes and home-ownership rates, a younger population, and a higher share of black or Hispanic households. Finally, the demographic characteristics of light rail neighborhoods fall between heavy and commuter rail stations. Specifically, light rail neighborhoods are characterized by much lower house rents and income than in heavy and commuter rail neighborhoods as well as a higher share of white households than in heavy rail neighborhoods and a higher share of renter households compared to commuter rail areas.

The descriptive statistics presented in this section highlight the differences between neighborhood types and rail modes, which vary in their built-environment and socio-demographic composition. The unique combination of built-environment factors and amenities like rail transit in each neighborhood are expected to have implications for the housing and transportation costs associated with a neighborhood type as well as for its affordability to low-income households. The next sections examine these relationships both longitudinally and cross-sectionally.

4.2. Housing Costs

4.2.1. A Longitudinal Analysis of Median Gross Rent

A major argument in the current housing-affordability debate is that housing costs have been increasing rapidly in recent decades to the point that they have become unaffordable to large portions of the population. At the heart of this debate are pedestrian-friendly neighborhoods, especially near rail stations, in which accessibility benefits that make a neighborhood more attractive are capitalized in the housing market. To this end, this section examines the factors that are associated with the change in rent between 1980, the start of the decade in which the new wave of light rail systems began, and 2017. In doing so, I test the hypothesis that rent increased over time at a faster rate in rail-oriented high-density neighborhoods than in lower-density rail and non-rail neighborhoods. While the analysis supports this argument, a second argument that the share of housing units in high-density non-rail or medium-density rail neighborhoods moderates the housing-cost increases in high-density rail neighborhoods is only partly supported.

The longitudinal analysis varies from the cross-sectional analysis in several aspects due to data availability limitations. First, since comparable historical data at the block-group level are limited, the unit of analysis in the longitudinal section is the census tract. In addition, historical data on walkability and transit job accessibility are also not available. As a result, the classification of census tracts to neighborhood types is based on density rather than a combination of density and walkability. Because of these differences, the first part of this section provides descriptive statistics of the longitudinal data set while the second sub-section provides a longitudinal multilevel analysis of median gross rent.

4.2.1.1. Descriptive Statistics of Neighborhood Types

Since 1980, median gross rent in the United States increased by 26%. This is similar to the rate of change in Minneapolis, the MSA at the 25th percentile of the rent-change among MSAs in this research. Rent gains, however, vary widely, from a low of 3.2% in Cleveland to 34% in Philadelphia, the median MSA, and up to 83% San Jose (Figure IV-5). Rent has also had different trajectories over time in different MSAs. Rent in most MSAs increased over time, but while Atlanta, Portland, and San Jose continued to experience rent increases until 2000, in Boston and Los Angeles, for example, average rents decreased between 1990 and 2000. Following the slowdown in the 1990s, rents began to increase more rapidly since 2000. These trends suggest that much of the affordability crisis that is experienced in recent years might be a result of the rent increases since 2000.

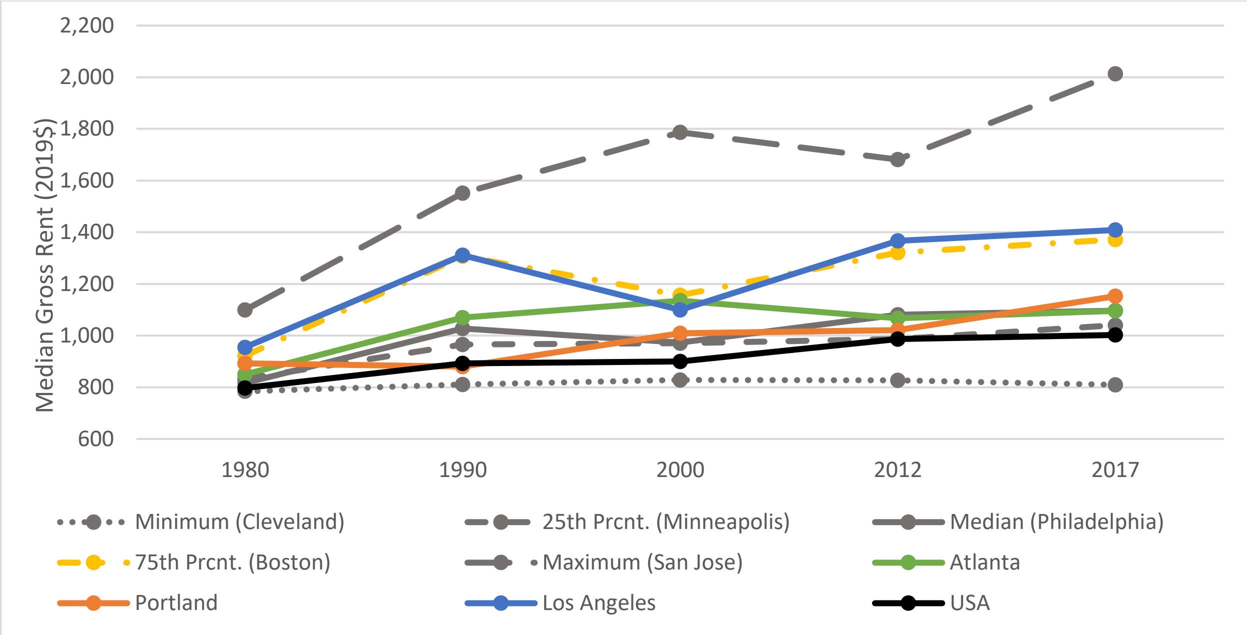

Figure IV-5: Median Gross Rent (1980-2017)

Table IV-5: Neighborhood Classification, Longitudinal Analysis

Neighborhood Type	Corresponding Rail Neighborhoods in the Cross-Sectional Analysis	Criteria	
		Housing Units per Acre	Distance to Rail
High Density Rail / Non-Rail	Transit-oriented development	≥8	750m (Euclidean distance) or within a 200m buffer
Medium Density Rail / Non-Rail	Rail-oriented intermediate development	<8 and ≥3	
Low Density Rail / Non-Rail	Transit-adjacent development	<3	

Table IV-6: Neighborhood Built-Environment Characteristics, Longitudinal Analysis, All Studied Metropolitan Areas

Neighborhood Type	Distance to CBD		Housing Units per Acre		% Single-Family		% Small Housing Units		% New Units	
	1980	2017	1980	2017	1980	2017	1980	2017	1980	2017
High Density Rail	10.2	9.9	32.1	32.3	5.7	6.6	75.2	73.4	5.7	6.5
High Density Non-Rail	12.1	14.4	15.3	15.7	17.0	16.5	71.1	70.0	10.1	9.9
Medium Density Rail	19.4	18.2	5.1	5.1	37.8	38.1	56.3	55.6	8.4	8.2
Medium Density Non-Rail	20.2	24.5	4.8	4.7	52.1	50.2	57.0	54.6	17.4	14.2
Low Density Rail	30.7	26.0	1.7	1.9	61.8	58.6	40.5	40.6	14.8	11.4
Low Density Non-Rail	29.2	32.0	1.5	1.9	67.3	65.2	39.4	37.7	38.1	28.9

Similar to the cross-sectional analysis, this section builds on the identification of six neighborhood types to examine how rent changed over time in different urban contexts (Table IV-5). This classification is based on census-tract housing-unit density and distance to a rail station but does not include a walkability component since walkability data are not available for previous decades. An effort was made to use classification criteria that correspond to those in the cross-sectional analysis and that would produce neighborhoods with similar characteristics.

The six types of neighborhoods differ from one another in their built-environment and socio-demographic characteristics and in the rate of change in these characteristics over time. The neighborhoods also differ from the neighborhoods in the cross-sectional analysis due to the different classification criteria, unit of analysis, and changes that occur over time. Despite the differences, the neighborhood types in this section also bear several important similarities to the neighborhood types in the cross-sectional analysis (Table IV-6). Similar to the neighborhoods in the cross-sectional analysis, neighborhoods that are closer to a rail station and the CBD tend to be denser, have smaller housing units, and fewer single-family housing units. New housing development, on the other hand, tends to occur farther from the CBD and from rail stations.

The built-environment characteristics of neighborhoods have remained fairly stable over time. The most notable changes are in distance from the CBD and the share of new housing units. Neighborhoods near a rail station in 2017 tend to be closer to the CBD than similar neighborhoods in 1980 while neighborhoods away from rail tend to be farther from the CBD in 2017 than in 1980. In terms of new housing development, the share of new housing units in lower-density and auto-oriented neighborhoods decreased over the years, while the share of new housing units in more central neighborhoods remained stable over time.

Table IV-7: Neighborhood Socio-Demographic Characteristics, Longitudinal Analysis, All Studied Metropolitan Areas

Neighborhood Type	Annual Median Gross Rent (2019$)		Median Income (2019$)		% White		% College or Higher		% Renter Housing Units	
	1980	2017	1980	2017	1980	2017	1980	2017	1980	2017
High Density Rail	8,201	16,691	49,421	51,676	49.5	34.5	28.2	41.4	77.3	73.6
High Density Non-Rail	8,385	15,697	47,986	46,411	53.5	32.6	30.4	42.8	65.9	64.4
Medium Density Rail	9,026	15,492	72,474	66,407	67.3	42.6	32.1	44.9	50.1	50.0
Medium Density Non-Rail	9,786	16,118	61,465	56,600	69.1	43.0	35.3	48.5	43.9	44.0
Low Density Rail	10,756	16,775	89,973	87,669	83.9	57.0	42.9	54.9	32.8	34.3
Low Density Non-Rail	10,987	17,343	61,785	62,454	83.2	59.4	42.3	56.6	28.1	29.2

Neighborhoods also differ in their socio-demographic composition and their change over time (Table IV-7). In 1980, as the distance from the CBD increases, neighborhoods tend to have higher rents, a larger share of white, educated, and home-owner households. Except in High-Density neighborhoods, median gross rent tends to be higher in non-rail neighborhoods than in their rail counterparts. Over time, neighborhoods have become more expensive and diverse. Specifically, since 1980, rents in medium- and high-density neighborhoods have increased at a faster rate than rents in low-density areas. Income, on the other hand, has remained fairly stable over time, with some neighborhood types even experiencing a decrease in real income between 1980 and 2017. This combination of increasing rents alongside stagnant incomes can explain why many households are struggling to afford housing.

Overall, the classification of census tracts based on housing density yields six neighborhood types that are relatively similar to the six neighborhood types in the cross-sectional analysis. At the same time, due to the use of census tracts instead of block groups, and the use of density as the sole criteria for identifying neighborhood types, the neighborhoods in this section differ from those in the cross-sectional analysis in some key characteristics. Hence, comparisons between the results in this section and the cross-sectional analysis are only suggestive.

4.2.1.2. A Longitudinal Analysis of Median Gross Rent (1980-2017)

After identifying the six neighborhood types, this section provides a longitudinal analysis on median gross rent. Specific emphasis is given to examining whether rents in higher-density rail-oriented neighborhoods increased at a faster rate than in other neighborhood types and whether housing in alternative medium- and high-density neighborhoods moderate the cost increases in high-density rail neighborhoods. To this end, a series of longitudinal multilevel regression models was fitted to examine the factors that are associated with a change in rent over time. The interclass correlation (ICC) of the unconditional intercept-only model, which indicates the share of the dependent variable that is explained by group-level factors, in this case metropolitan areas, is 0.231. In other words, 23% of the variation in median gross rent among census tracts is explained by the metropolitan grouping. This is a high ICC value, which lends further support to the analysis of housing costs using multilevel regression.

Particular attention is given to examining the change in rent in different neighborhood types. The unit of analysis in these regression models is the census tract, which are grouped into twenty-seven metropolitan areas. The dependent variable in all the models is Annual Median Gross Rent, represented in thousands in 2019$. The models maintain a similar set of control variables and vary from one another in their key explanatory variables. Change in rent is examined over five time-points: 1980, 1990, 2000, 2012 (2008-2012 data), and 2017 (2013-2017 data). The reference year in the Year dummy variable was set to 2000 to represent the middle time-point in the analysis and to better capture variation over shorter periods of time. Because dummy variables test the difference between the reference group and other groups, an increase in rent over time will be evident by a negative sign assigned to 1980 and 1990 coefficients and a positive sign for 2012 and 2017 coefficients.

Table IV-8: Neighborhood Type Models, Longitudinal Analysis. Dependent variable: Annual Median Gross Rent (1000s)

	Neighborhood Type	CBD Distance	Neighborhood Type by Year
VARIABLES	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)
Block-group Level			
% Black	-0.029***	-0.030***	-0.030***
	(0.0004)	(0.0004)	(0.0004)
% Hispanic	-0.037***	-0.039***	-0.038***
	(0.0005)	(0.0005)	(0.0005)
% Age 25-39	0.085***	0.083***	0.079***
	(0.002)	(0.0017)	(0.0016)
% Small Housing Units	-0.041***	-0.042***	-0.041***
	(0.0005)	(0.0005)	(0.0005)
% New Development	0.034***	0.035***	0.034***
	(0.0005)	(0.0006)	(0.0006)
Year (Reference: 2000)			
1980	0.376***	0.352***	0.379***
	(0.115)	(0.115)	(0.1194)
1990	0.215**	0.211**	0.420***
	(0.089)	(0.0888)	(0.0933)
2012	1.997***	2.006***	1.789***
	(0.086)	(0.0859)	(0.0932)
2017	1.178***	1.216***	1.086***
	(0.086)	(0.0857)	(0.0932)
Median Household Income (1000s)	0.046***	0.045***	0.0451***
	(0.0006)	(0.0006)	(0.0006)
1980	-0.017***	-0.017***	-0.018***
	(0.0008)	(0.0008)	(0.0009)
1990	-0.009***	-0.009***	-0.011***
	(0.0007)	(0.0007)	(0.0008)
2012	0.010***	0.010***	0.012***
	(0.0008)	(0.0008)	(0.0008)
2017	0.042***	0.042***	0.044***
	(0.0006)	(0.0008)	(0.0008)
Distance from CBD (KM, 1000s)		-0.009***	-0.009***
		(0.0006)	(0.0006)
Neighborhood Type (Reference: Low-Density Non-Rail)			
Low Density Rail	-0.170***	-0.213***	-0.308***
	(0.049)	(0.0489)	(0.1032)
1980			0.377**
			(0.164)
1990			0.511***
			(0.1537)
2012			0.096

			(0.1426)
2017			-0.175
			(0.1417)
Medium Density Non-Rail	0.010	-0.054**	-0.0725
	(0.024)	(0.0248)	(0.0501)
1980			-0.009
			(0.0712)
1990			-0.295***
			(0.069)
2012			0.321***
			(0.0701)
2017			0.121*
			(0.0704)
Medium Density Rail	-0.166***	-0.281***	-0.603***
	(0.044)	(0.0450)	(0.094)
1980			0.472***
			(0.1453)
1990			0.034
			(0.1348)
2012			0.732***
			(0.1270)
2017			0.475***
			(0.1261)
High Density Non-Rail	0.220***	0.054	0.099
	(0.035)	(0.0368)	(0.0709)
1980			-0.185*
			(0.0958)
1990			-0.615***
			(0.0947)
2012			0.356***
			(0.0967)
2017			0.301***
			(0.0964)
High Density Rail	0.763***	0.546***	0.498***
	(0.041)	(0.0439)	(0.0819)
1980			-0.062
			(0.1134)
1990			-0.911***
			(0.1098)
2012			0.367***
			(0.1090)
2017			0.842***
			(0.1080)
Metropolitan Level			
Population (Mil.)	0.250***	0.273***	0.272***
	(0.021)	(0.022)	(0.0217)
1980	0.041***	0.045***	0.046***
	(0.006)	(0.0058)	(0.0065)
1990	-0.011*	-0.007	0.012*

	(0.006)	(0.0062)	(0.0067)
2012	0.047***	0.046***	0.042***
	(0.005)	(0.0053)	(0.0058)
2017	0.051***	0.049***	0.033***
	(0.005)	(0.0050)	(0.0054)
Median House Value (1000s)	0.016***	0.016***	0.016***
	(0.0004)	(0.0004)	(0.0004)
1980	-0.006***	-0.007***	-0.006***
	(0.0005)	(0.0005)	(0.0005)
1990	-0.002***	-0.002***	-0.001***
	(0.0003)	(0.0003)	(0.0003)
2012	-0.006***	-0.006***	-0.007***
	(0.0003)	(0.0003)	(0.0003)
2017	-0.007***	-0.007***	-0.007***
	(0.0003)	(0.0003)	(0.0003)
Constant	5.105***	5.610***	5.637***
	(0.290)	(0.3031)	(0.3027)
Observations	110,700	110,700	110,700
Number of groups	27	27	27
Wald test	203117***	205234***	206484***
Linear Regression test	13592***	13658***	13492***

*** p<0.01, ** p<0.05, * p<0.1

The main question addressed in this section is whether the rate of change in rent varies by neighborhood type. If housing near rail increases at a faster rate than away from rail, we could expect housing to become less affordable over time. Therefore, the first set of regression models in this examines the association between neighborhood types and median gross rent over time (Table IV-8). The Neighborhood Type models were constructed without any rail-specific variables since including the variable for distance from a rail station leads to the omission of a large number of observations in metropolitan areas that did not have rail service in a specific data year, mainly in 1980 and 1990. Instead, the neighborhood type dummy variables capture the effect of proximity to rail.

Overall, the models perform well and the results for the control variables are in the expected direction (Table IV-8). Notably, the models also show that the change in rent over time is not linear. Specifically, the coefficient for Year suggests that, holding other variables constant, while rents have increased fairly rapidly between 2000 and 2012/2017, they have actually decreased in the prior two decades, between 1980/1990 and 2000. In addition, median income at the census tract and the population of a metropolitan area are both positively associated with rent, and the effect sizes of these relationships increase over time. On the other hand, while the association between median house value at the metropolitan level and median gross rent is also positive, its interaction with the year dummy variable also suggests that the effect of the metropolitan housing market on rent has been weakening since the year 2000. This might suggest that the rental housing market has been gradually diverging from the owner-occupied housing market. Finally, including the CBD distance variable seems to capture some of the effect associated with neighborhood types, as some of the neighborhood coefficients shrink and others lose their statistical significance relative to low-density non-rail neighborhoods (CBD Distance Model). This suggests that distance to the CBD is an appropriate proxy for transit job accessibility as it captures some of the accessibility benefits that are associated with rail-proximate neighborhoods.

Compared to rent in Low-Density Non-Rail neighborhoods, median gross rents are lower in medium- and low-density rail-oriented neighborhoods but are higher in high-density rail neighborhoods (Neighborhood Type by Year Model). These results are consistent with those in the cross-sectional analysis and suggest that, after controlling for transit accessibility benefits via the distance to the CBD, proximity to a rail station provides added benefits only in neighborhoods with very high densities. One explanation for these results is that, relative to other neighborhoods, these neighborhoods tend to be closer to the CBD and have a better mix of different land uses.

Interacting the Neighborhood Type variables with Year shows that rents in medium- and high-density rail and non-rail neighborhoods have been increasing since 1990 relative to rent in low-density non-rail neighborhoods (Neighborhood Type by Year Model; Figure IV-6).

Specifically, since 1990, rents in medium- and high-density rail neighborhoods have increased at a faster rate than rents in their non-rail counterparts. Moreover, high-density rail neighborhoods are the only neighborhood type in which rents have increased at a faster rate between 2000 and 2017 than between 2000-2012. To the extent that rent reflects the value that society assigns to housing in a specific neighborhood, the increase in rent in rail and non-rail pedestrian-friendly environments over time suggests that, since 1990, these neighborhoods have become more attractive to housing consumers.

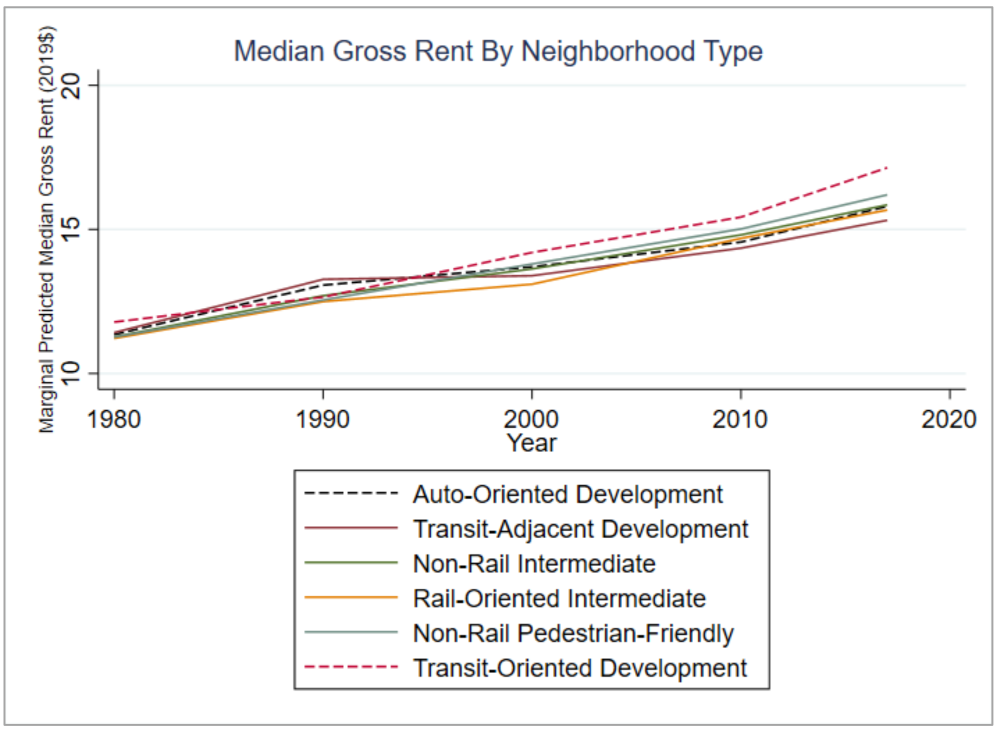

Figure IV-6: Predicted Change in Median Gross Rent by Neighborhood Type, 1980-2017

Table IV-9: Neighborhood Housing Supply, Longitudinal Analysis, Dependent Variable: Annual Median Gross Rent (1000s; 2019$)

	Housing Units per 100,000 Residents		% High-Density Rail Housing Units		% High-Density Non-Rail Housing Units		% Medium-Density Rail Housing Units	
Variables	Sign	Sig.	Sign	Sig.	Sign	Sig.	Sign	Sig.
% Housing Units	+		+		+	***	-	
Low-Density Rail	-		+	**	-		-	
Medium Density Non-Rail	-		-		-	***	-	***
Medium Density Rail	-	***	+	***	-	***	-	
High Density Non-Rail	-		+		-	***	-	***
High Density Rail	-	***	+	***	-	***	+	***
% Housing Unit								
1980	-	***	+		-	***	+	
1990	-	**	+	***	+	***	+	***
2012	-		+		+	***	-	
2017	-		-	***	+	**	-	**
% Housing Unit * Low-Density Rail								
1980	+		-		+	*	+	*
1990	-		-		+		+	
2012	+		-	***	-		-	
2017	+		-	***	-		-	
% Housing Unit * Medium Density Non-Rail								
1980	+		-		+	***	+	
1990	+		-	***	+		-	
2012	-		+		+	***	+	***
2017	+		+	***	+	*	+	***
% Housing Unit * Medium Density Rail								
1980	+	**	-		+	**	+	
1990	+	***	-	***	-		+	*
2012	+		-		+		+	***
2017	+	**	+		+		+	***
% Housing Unit * High Density Non-Rail								
1980	+	***	-		+	***	+	*
1990	+	***	-	***	-		-	
2012	+		+		+	***	+	***
2017	-		+	***	+		+	***
% Housing Unit * High Density Rail								
1980	+	***	-		+	***	-	***
1990	+	***	-	***	-		+	
2012	+		-		+	*	+	
2017	-		+	***	+		-	

*** p<0.01, ** p<0.05, * p<0.1
Full models presented in Table VII-3. Sig.: Statistical significance.

A second important question this research explores is whether a larger supply of housing in neighborhoods with somewhat similar characteristics to the highly-demand high-density rail neighborhoods moderates the housing-cost increases in the latter neighborhood type. If this is indeed the case, the results will have implications to the types of neighborhoods that housing planners should aim to develop and within which transportation planners should locate rail stations. The longitudinal analysis allows testing this hypothesis by examining how a change in the supply of housing units over time in different types of neighborhoods is associated with rent in high-density rail neighborhoods. The results from the longitudinal neighborhood housing supply models (Table IV-9; Table VII-3) largely support the argument that a higher share of high-density non-rail housing units has a moderating effect on rents in the different types of neighborhoods. On the other hand, the share of housing units in medium-density rail neighborhoods does not seem to have as strong an effect while the share of housing units in high-density rail neighborhoods has an amplifying effect.

Moreover, the models also show that the effect that is associated with each measure of housing supply has a different temporal trend. On the one hand, an increase over time in the share of housing units in high-density non-rail neighborhoods is positively associated with rents. On the other hand, an increase over time in the share of housing units in high-density rail neighborhoods is negatively associated with rent, especially between 1990-2000 and 2000-2017. However, the models do not show a consistent and statistically significant relationship over time between each measure of housing supply and median gross rent in specific neighborhood types. Combined, these results suggest that the increase in the supply of housing in high-density rail development over time weakens the amplifying effect on rent that is associated with this neighborhood type. At the same time, the results also suggest that an increase in the supply of housing in high-density non-rail development over time weakens the moderating effect on rent that is associated with this neighborhood type.

Overall, the results in this section support the arguments made in Hypothesis 1. First, the results indicate that rent-increases are more pronounced in high-demand neighborhoods such as those with high densities and near a rail station. In addition, the results also support the argument that increasing the supply of housing over time, especially in high-density non-rail development, can also moderate the higher housing costs that are found in TODs.

4.2.2. A Cross-Sectional Analysis of Median Gross Rent

In this sub-section, I combine data from 27 metropolitan areas with an intra-urban rail system to examine the association between neighborhood and metropolitan factors and rent at the neighborhood level. Specifically, several hypotheses (Hypothesis 2) are tested about the relationships between transportation benefits and rent in different neighborhood types, as well as how metropolitan-level constraints on housing supply and the supply of housing in different neighborhood types are associated with rent at the neighborhood level. The results support the hypotheses that transportation benefits and land-use regulation that constrain multi-family development are associated with higher rents. On the other hand, a larger supply of housing in neighborhoods that serve as alternatives to transit-oriented development is associated with a moderating effect on rents.

Housing costs are commonly explained, among other things, as a function of housing and market conditions, built-environment characteristics, and transportation level of service. However, even after controlling for these factors, housing costs might still vary from one metropolitan area to another due to unobserved metropolitan-level factors. Indeed, the interclass correlation from the unconditional random intercept model is 0.233, indicating that 23% of the variance in median gross rent across block groups is explained by variations between metropolitan areas. This is a relatively high Interclass Correlation value which, alongside theoretical considerations, justifies the multilevel approach that is adopted in this analysis.

The regional variation is further evident from a metropolitan fixed-effects model with Denver, the MSA at the median of median gross rent distribution, as the reference MSA (Figure IV-7). Except for two MSAs (Austin and Seattle) with median rents close to those in Denver, the difference in rents between each MSA and Denver is statistically significant at the 5% or 1% levels. The results from the model suggest that, after controlling for neighborhood, socio-demographic, and transportation characteristics, metropolitan differences account for a gap in average rent, which ranges from close to \$-4,000 between Buffalo or Pittsburgh and Denver to almost \$+4,500 between Denver and San Diego and Los Angeles.

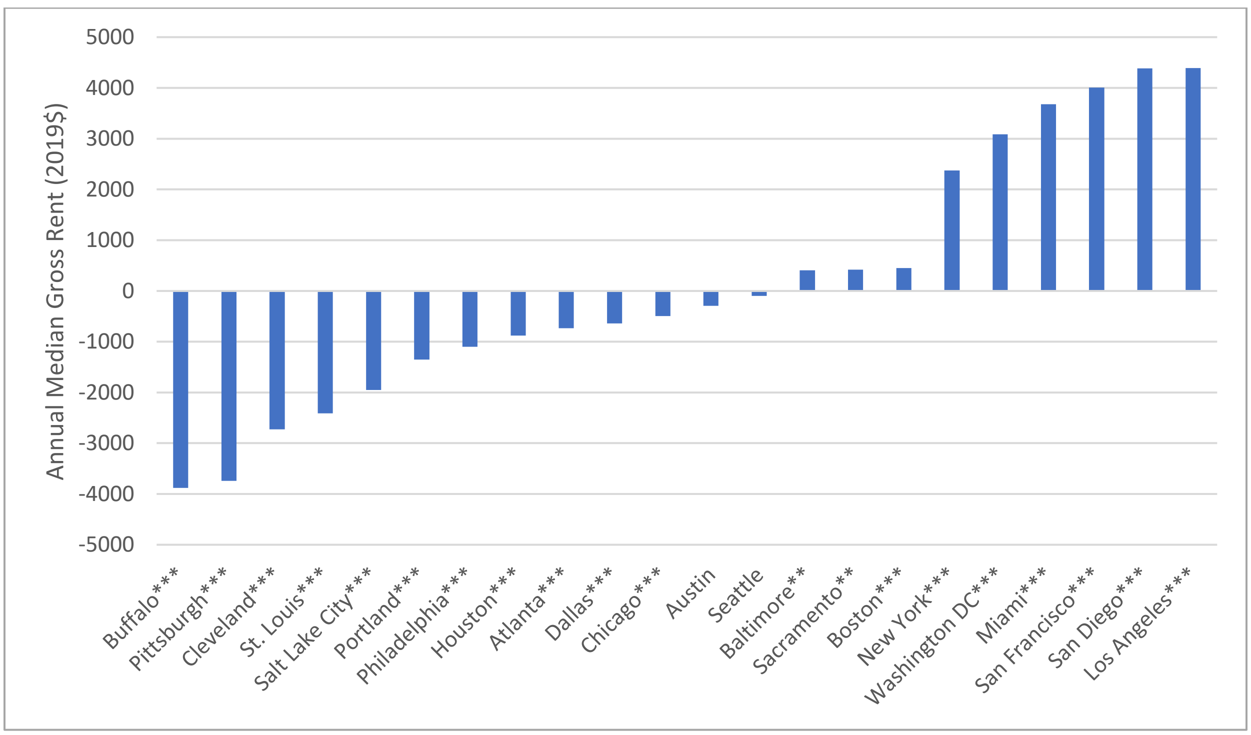

Figure IV-7: Metropolitan Fixed-Effects
*** p<0.01, ** p<0.05, * p<0.1
Note: Reference MSA: Denver. Excluding four MSAs without transit accessibility data: Charlotte, Minneapolis, Phoenix, and San Jose.

Ranking the metropolitan areas by annual median gross rent (Table IV-10) suggests that housing costs are higher in MSAs with higher incomes and house values. Housing costs also tend to be higher in regions with higher housing unit densities and to a lesser degree also levels of transit accessibility. Transportation costs also tend to be higher in MSAs with higher incomes, but this relationship is somewhat mediated by the effect of higher transit accessibility and density in high-income MSAs. These distributions indicate a potential tradeoff between housing and transportation costs in most MSAs.

Table IV-10: Metropolitan Descriptive Statistics

MSA	Annual Median Gross Rent (2019$)	Estimated Annual Average Transport Costs (2019$)	Pop. (Mil.)	Annual Median Income (2019$)	Median House Value (2019$)	Housing -Units per Acre	30-minute Transit Access	Average Housing Afford.	Average Trans. Afford.
San Jose	24,142	15,430	1.7	102,888	749,835	3.9	N/A	21.3	13.6
San Francisco	21,271	13,166	3.4	83,533	683,961	3.9	238,494	19.6	12.1
Washington DC	20,357	11,815	4.9	100,280	429,405	2.8	358,953	17.5	10.2
San Diego	19,344	13,695	3.1	68,044	457,925	3.3	85,054	24.9	17.6
Los Angeles	18,819	13,525	12.5	62,960	493,576	4.2	263,754	28.1	20.2
New York	17,710	10,061	18.8	70,707	435,151	4.1	784,528	26.1	14.8
Boston	16,620	11,739	4.3	79,286	398,649	2.2	260,467	15.9	11.2
Seattle	16,563	13,019	3.2	74,540	348,526	2.4	129,149	17.4	13.7
Miami	16,490	11,593	5.8	51,918	209,967	3.6	85,200	31.1	21.8
Sacramento	15,578	13,339	1.8	63,460	290,846	2.5	70,789	20.5	17.5
Baltimore	15,551	11,393	2.3	71,128	277,118	2.5	152,974	16.3	11.9
Denver	15,243	12,505	2.5	68,418	275,841	2.8	150,732	17.9	14.7
Austin	14,922	12,416	1.5	69,106	231,996	2.1	118,091	18.3	15.2
Phoenix	14,276	12,579	3.8	56,727	194,110	2.5	N/A	20.9	18.5
Portland	14,194	12,389	1.9	63,507	286,696	2.8	124,153	18.1	15.8
Atlanta	13,838	12,500	4.7	61,465	183,468	1.6	53,049	19.0	17.2
Dallas	13,780	12,560	5.4	61,720	161,971	2.2	89,801	18.4	16.8

Chicago	13,688	11,589	8.7	65,561	233,486	2.8	216,371	16.9	14.3
Salt Lake City	13,630	13,502	1.1	65,881	248,491	2.5	131,738	17.7	17.6
Philadelphia	13,558	11,250	5.5	65,251	247,427	2.4	230,722	15.7	13.0
Minneapolis	13,158	12,135	2.7	72,117	228,271	2.1	N/A	14.3	13.2
Houston	12,858	12,445	5.3	62,920	158,034	2.4	144,242	17.4	16.9
Charlotte	12,124	12,325	1.3	63,722	206,774	1.4	N/A	17.0	17.2
St. Louis	11,050	11,737	2.2	58,359	170,378	2.0	88,206	14.8	15.7
Cleveland	10,267	10,901	1.8	53,204	148,030	2.3	105,060	14.6	15.5
Pittsburgh	9,934	11,037	1.7	56,675	143,241	1.9	105,282	13.4	14.9
Buffalo	9,453	10,991	0.9	52,309	128,875	2.3	93,667	12.9	15.0

Notes: Metropolitan areas are ordered according to annual median gross rent.

Within an MSA, annual median gross rent varies by the location of a neighborhood within the region and the specific characteristics of that location (Figure IV-8). In Boston, the most rail-oriented MSA among the four mapped MSAs, higher rents tend to concentrate around rail stations in the central areas of the MSA and to decline with distance from the CBD. In Atlanta and Los Angeles, on the other hand, rents tend to increase with distance from the CBD, perhaps due to higher crime rates closer to downtown, larger houses farther from downtown and because these are more auto-oriented and polycentric metropolitan areas, which reduce the benefits of central locations. Finally, Portland does not exhibit a distinct geographic pattern of rent distribution, though the eastern areas of the MSA tend to be less expensive, perhaps because of the relatively large migration of low-income and minority households from more central locations to these areas in recent decades (Goodling et al., 2015).

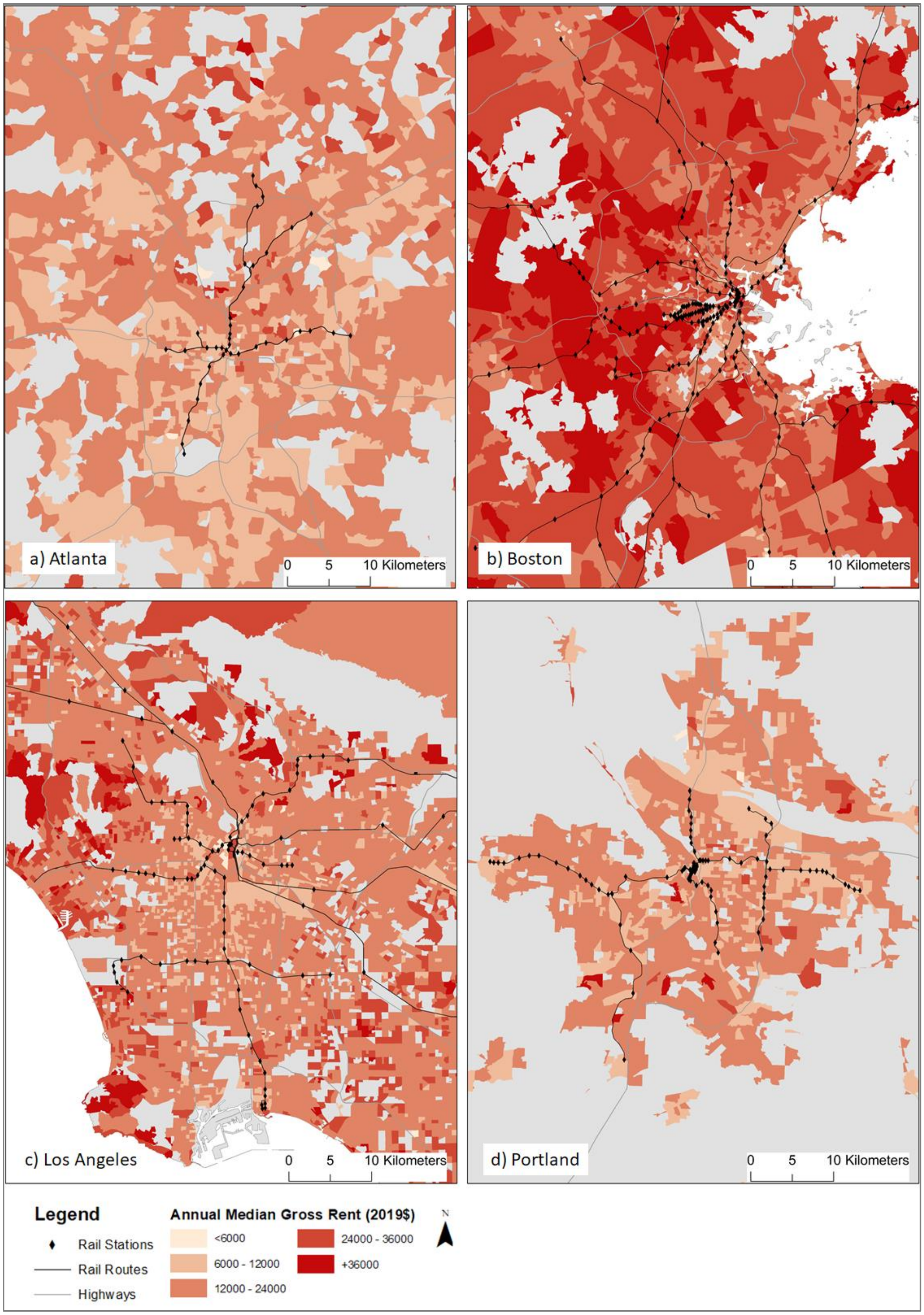

Figure IV-8: Annual Median Gross Rent ($2019) in Select MSAs

To provide a more in-depth analysis of the locational factors that are associated with housing costs, a set of multilevel regression models was constructed to estimate the effects on annual median gross rent that are associated with the six neighborhood types and with transportation level of service (Table IV-11). Overall, the models suggest that a pedestrian-friendly built-environment, especially near rail, has a positive effect on housing costs relative to auto-oriented development (Neighborhood Type Model). However, including transportation characteristics in the models also suggests that much of the cost-premiums that are associated with pedestrian-friendly neighborhoods stem from their transportation benefits rather than their built environments (Rail Distance and Accessibility Models). After accounting for transportation characteristics, the effect sizes associated with all neighborhood types shrink considerably.

Table IV-11: Neighborhood Types and Transportation Models, Cross-Sectional. Dependent variable: Annual Median Gross Rent (2019$)

	Base Model	Neighborhood Type Model	Rail Distance Model	Accessibility Model
VARIABLES	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)
Block-Group Level				
% Black	-11.109***	-11.366***	-13.698***	-13.942***
	(0.843)	(0.847)	(0.878)	(0.878)
% Hispanic	-21.955***	-22.577***	-24.814***	-25.301***
	(1.086)	(1.085)	(1.107)	(1.110)
% Age 25-39	46.068***	41.507***	39.315***	35.396***
	(2.004)	(2.039)	(2.050)	(2.060)
Average Household Size	45.175	63.467*	68.351*	69.360*
	(38.002)	(37.935)	(37.903)	(37.996)
% Small Housing Units	-33.762***	-36.024***	-36.998***	-39.219***
	(1.007)	(1.044)	(1.049)	(1.054)
% New Development	24.053***	23.370***	24.891***	25.243***
	(1.226)	(1.228)	(1.237)	(1.236)
Median Household Income (1000s)	96.693***	96.257***	95.000***	94.164***
	(0.728)	(0.727)	(0.739)	(0.740)
Neighborhood Type (Reference: Auto-oriented)				

Transit-adjacent		-406.608***	-517.517***	-569.893***
		(107.645)	(108.703)	(108.639)
Non-rail intermediate		-31.911	-164.178***	-171.210***
		(45.376)	(47.257)	(47.223)
Rail-oriented intermediate		577.155***	369.492***	-159.219**
		(72.498)	(75.591)	(80.870)
Non-rail pedestrian-friendly		161.859**	-34.122	-76.268
		(73.142)	(75.916)	(75.793)
Transit-oriented		1,363.827***	1,109.819***	474.955***
		(95.598)	(99.092)	(104.984)
			-29.347***	-32.758***
Distance to Highway Ramp (Km)			(10.567)	(10.581)
Distance to Rail (Km)			-3.364	-9.307***
			(2.458)	(2.483)
Distance to CBD (Km)			-8.819***	0.564
			(1.211)	(1.320)
Job Accessibility				0.853***
				(0.048)
Metropolitan Level				
Population	0.157**	0.147**	0.161**	0.135*
	(0.072)	(0.074)	(0.076)	(0.076)
	13.031***	12.964***	12.989***	12.845***
Median House Value (1000s)	(2.122)	(2.177)	(2.252)	(2.241)
Constant	5,127.729***	5,350.851***	5,873.345***	6,029.885***
	(656.529)	(673.039)	(697.591)	(694.344)
Observations	52,819	52,818	52,818	52,573
Number of groups	23	23	23	23
Wald test	52761***	53334***	53531***	54078***
Linear Regression test	4038***	4206***	4205***	4180***

*** p<0.01, ** p<0.05, * p<0.1

The socio-demographic and housing control variables (Table IV-11: Base Model), which are used in all of the models in this sub-section, produce consistent results and in the expected direction. According to the Base Model, variables that are associated with lower-income households, like the share of black or Hispanic households and the share of small housing units, are associated with lower housing costs. On the other hand, block groups with larger average household sizes, higher shares of households with people aged 25-39, higher shares of new housing development since 2000, and higher median income are associated with higher median gross rents.

At the metropolitan level, larger metropolitan areas and those with a more expensive housing market are both positively associated with block-group rent.

After controlling for socio-demographic, housing, and metropolitan-level characteristics, proximity to a rail station, together with a pedestrian-friendly built environment, provides a rent-premium over auto-oriented development (Table IV-11: Neighborhood Type Model). The variable 'Neighborhood Type' is a categorical variable that compares rent in auto-oriented development (the reference category) to rent in each of the five additional neighborhood types. The interpretation of the Neighborhood Type Model suggests that TODs have the highest rent-premium over auto-oriented development, followed by rail-oriented intermediate development and non-rail pedestrian-friendly development. On the other hand, auto-oriented neighborhoods near rail (i.e., transit-adjacent development) are valued less than their non-rail counterparts (i.e., auto-oriented development). These results suggest proximity to a rail station has a differential effect on rent depending on neighborhood built-environment characteristics. Specifically, proximity to a rail station provides a rent-premium in neighborhoods with medium and high levels of pedestrian-friendly environments but proximity is viewed as a disutility in auto-oriented rail-adjacent development.

The results from the Neighborhood Type model, however, do not distinguish between the effects that are associated with a neighborhood's built-environment and those that are associated with its transportation characteristics. This is an important distinction from the perspective of location affordability since transportation-cost savings from better transportation services are more likely to compensate for the rent-premiums that are associated with transportation benefits than for premiums that are associated with neighborhood built-environment benefits.

Therefore, two additional models were constructed to account for neighborhood transportation characteristics. The first model includes distance to the nearest highway ramp, rail station, and the MSA's CBD (Rail Distance Model), while the second also includes transit job accessibility (Accessibility Model). The transportation characteristics in these models perform as expected. The results suggest that transportation characteristics provide a benefit that is capitalized in the rental housing market. Specifically, an increase in the distance from a highway ramp (a proxy for private-vehicle accessibility), as well as distance from a rail station and the CBD (proxies for job accessibility) are all negatively associated with rent (Rail Distance Model). This suggests that housing closer to a highway ramp and the CBD are more expensive, presumably because of the accessibility benefits associated with these characteristics.

In addition, transit job accessibility is positively associated with rent (Accessibility Model). This finding supports the argument that a better transit level of service provides a benefit that is captured in the housing market in the form of higher rents. Specifically, an increase of 1-million jobs that are accessible by transit, which represents the difference in transit job accessibility between TOD and transit-adjacent development, is associated with an increase of $853 in rent. Moreover, the effect that is associated with distance to the CBD becomes positive and not statistically significant once transit job accessibility is accounted for, which suggests that distance to the CBD is a proxy for transit job accessibility, as the bid-rent theory and previous studies assume. These results indicate that access to transit, both in the form of proximity to a rail station and as transit accessibility, has a positive association with housing costs.

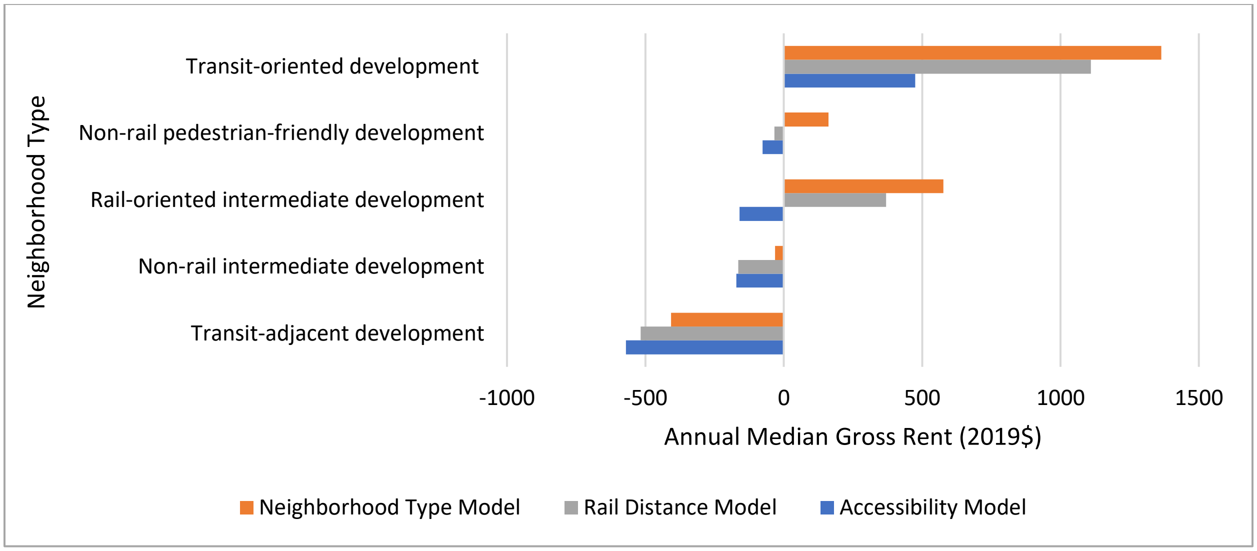

Figure IV-9: Neighborhood-Type Effect Size Relative to Auto-Oriented Development, based on models from Table IV-11

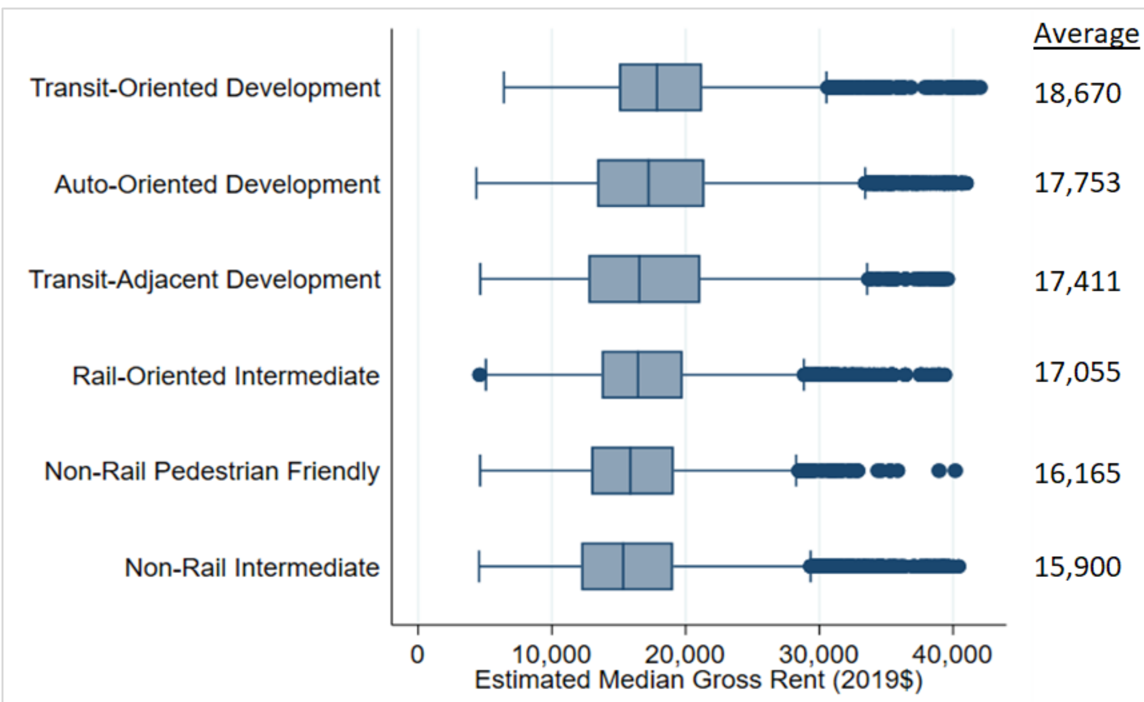

Figure IV-10: Estimated Annual Median Gross Rent by Neighborhood Type, based on the Accessibility Model

Accounting for the transportation characteristics at the neighborhood level also reveals that the rent-premium that is associated with the different neighborhood types relative to auto-oriented development stems, for the most part, from the transportation benefits that are associated with each neighborhood type. Specifically, the effect sizes that are associated with each neighborhood type shrink considerably after including the distance variables and accounting for transit job accessibility (Table IV-11; Figure IV-9). However, the degree of change in effect size from one model to the other varies by neighborhood type, which suggests that transportation characteristics do not have a uniform effect on the relationship between neighborhood type and rent. Including the distance variables has a stronger effect on the rent-premiums that are associated with non-rail and low-density rail neighborhoods. At the same time, accounting for transit job accessibility has a stronger effect on the rent-premiums that are associated with TODs and rail-oriented intermediate development, the two rail-proximate pedestrian-friendly neighborhood types. Hence, rent in non-rail and low-density neighborhoods seems to be affected by distance to the CBD and the nearest highway ramp, while rent in rail-proximate pedestrian-friendly neighborhoods is mostly affected by transit job accessibility.

Even after accounting for transit level of service, TODs still show a rent-premium over auto-oriented development (Accessibility Model; Figure IV-9). Specifically, after for accounting transit accessibility, TODs still have a $475 rent-premium over auto-oriented development. This suggests that the pedestrian-friendly built environment that is found in TODs provides a benefit that is captured in the rental housing market above and beyond the transportation benefits that are associated with the location. This effect is not found in rail-oriented intermediate development, however, perhaps due to the lower levels of walkability that are found in these neighborhoods or because they tend to be located farther from the CBD. Hence, rent in TODs might be higher not only because of the higher transit level of service they provide but also because their built environment is viewed as a benefit by housing consumers.

Calculating the regression equation for each neighborhood type reveals that, on average, rent is highest in TODs, followed by auto-oriented and transit-adjacent development, and lowest in non-rail pedestrian-friendly and intermediate neighborhood types with the highest housing costs (Figure IV-10). The factors that contribute to this distribution of rents across neighborhoods seem to vary by neighborhood types. Specifically, despite having a larger share of small housing units, TODs seem to be more expensive due to a high share of new housing units as well as to their transit-accessibility and walkability benefits. On the other hand, auto-oriented and transit-adjacent development seem to be expensive as a result of larger homes and new housing units, as evident from their lower share of small housing units and larger shares of single-family and new housing units.

This analysis also suggests that rail-oriented intermediate neighborhoods and non-rail pedestrian-friendly development might serve as central, yet affordable, alternatives to TODs. The rents in these neighborhoods are, on average, about \$1,500-\$2,500 lower than in TODs, respectively, despite enjoying relatively high levels of transit accessibility, density, and walkability. Yet, the characteristics of these neighborhoods do not translate into higher rents. First, housing units in these neighborhoods tend to be small and, therefore, less expensive. More importantly, the combination of transit accessibility, density, and walkability in these neighborhoods do not produce a highly pedestrian-friendly environment that incentivizes new housing development.

Table IV-12: Land-Use Regulations Variables, Definitions

Variable	Source	Definition
Wharton Index	Gyourko, Saiz, & Summers (2008)	Standardized Wharton Index, which combines the results from over 100 variables.
Multi-Family Approval Time	Self-calculated; inspired by Glaeser, Gyourko, & Saks (2006)	Combines two variables from the Wharton data set: 1) The average length of time for re-zoning permits to be approved; 2) the average length of time for subdivision permits to be approved.
Multi-Family Constraints	Self-calculated	Combines three variables from the Wharton data set: 1) Density restrictions on multi-family housing; 2) length of zoning process for multi-family housing; 3) length of permit process for multi-family housing.

If increasing the supply of housing units can moderate housing-cost increases, as many housing advocates argue, then land-use regulations that restrict the supply of housing should be associated with higher median gross rent. Three variables were constructed using data from the Wharton Residential Land Use Regulatory Index (Gyourko et al., 2008) to test the association between land-use regulations at the metropolitan level, and especially regulations that constrain multi-family development, and block-group rent (Table IV-12). Because the Wharton land-use regulations data are only reported at the city or municipality level, each variable was constructed using data on the central city in each of the MSAs in the research. In addition, since the units of the Wharton data do not bear a significant meaning, standardized values were constructed with a mean of 0 and a standard deviation of 1 to allow for a more meaningful interpretation.

The high end of the Wharton Index is dominated by West coast cities while the bottom of the distribution is dominated by legacy rust-belt cities (Figure IV-11). Overall, the difficulty of developing multi-family housing tends to decrease with a decrease in the Wharton Index. In cities with higher Wharton Index values, it tends to take a longer time to re-zone for multi-family use and to receive a permit for housing subdivisions (Multi-Family Approval Time variable). The Multi-Family Constraints variable, on the other hand, seems to have a weaker association with the Wharton Index, as some MSAs with higher rents but lower Wharton Index values rank higher on the Constraints variable. Hence, while the figures in Figure IV-11 are only descriptive, the relationship between land-use regulations and median gross rent seems to be associated more with restrictions on multi-family and dense development than with the aggregated Wharton Index. Specifically, average block-group median gross rent tends to be higher in MSAs in which its central city constrains dense development and where it takes a longer time to re-zone and receive a permit for multi-family housing.

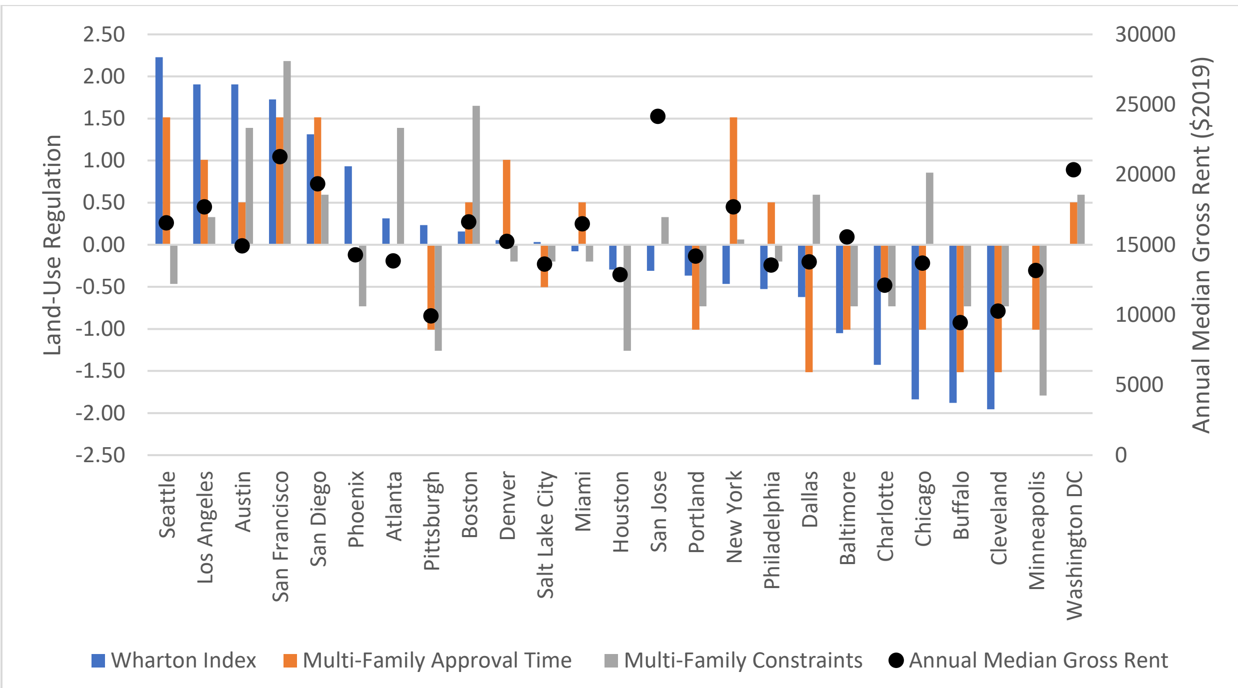

Figure IV-11: Land-Use Regulations Variables, Descriptive Statistics, All Studied Metropolitan Areas

Notes: 1) MSAs are ordered by the Wharton Index. 2) Values are in standard deviation. 3) Minneapolis and Washington DC are missing data on the Wharton Index.

A set of multi-level regression models was constructed with cross-level interactions between land-use regulations at the metropolitan level and neighborhood types at the block-group level to examine the association between land-use regulations and median gross rent in each of the six neighborhood types (Table VII-1). The positive slopes of the marginal effects of the cross-level interactions between land-use regulations and neighborhood types suggest that more stringent land-use regulations are associated with higher rents across all neighborhood types. Yet the different slopes for each neighborhood type also suggests that effect sizes vary by the type of regulations and neighborhood (Figure IV-12). Overall land-use regulations (Wharton Index Model) and constraints on the approval time for multi-family development (Multi-Family Development Approval Time Model) have a positive association with rent. However, the slope for auto-oriented development is steeper than those for pedestrian-friendly neighborhood types. These results suggest that overall land-use regulations and the longer time it takes to develop multi-family housing results in higher costs in auto-oriented development relative to the other neighborhood types.

On the other hand, constraints on density and multi-family housing development (Multi-Family Constraints Model) has a steeper slope for TODs, perhaps because these constraints limit the ability to increase the supply of housing in this neighborhood type. Rents in non-rail pedestrian-friendly development seem to be affected the least by all three measures of land-use regulations, perhaps because there is less pressure to develop in these neighborhoods. Combined, these results suggest that land-use constraints, and especially those that limit the ability to provide pedestrian-friendly environments across an MSA, are associated with higher housing costs in all neighborhood types, including in low-density auto-oriented neighborhoods.

Following the same logic behind the land-use regulations models, if housing in rail-proximate pedestrian-friendly neighborhoods is expensive because of its scarcity at the regional scale, as housing advocates often argue and as research suggests, then increasing the share of housing in similar and alternative neighborhoods regionwide ought to moderate the housing cost that is associated with each neighborhoods. To test this hypothesis, four multilevel regression models were constructed to examine how the supply housing units in a metropolitan area and different neighborhood types are associated with median gross rent (Figure IV-13; Table IV-13). The results from these models suggest that increasing the share of housing units in neighborhoods that serve as alternatives to TODs might be a more effective approach to reducing housing costs near rail stations than through increasing housing supply anywhere in the MSA or specifically in TODs.

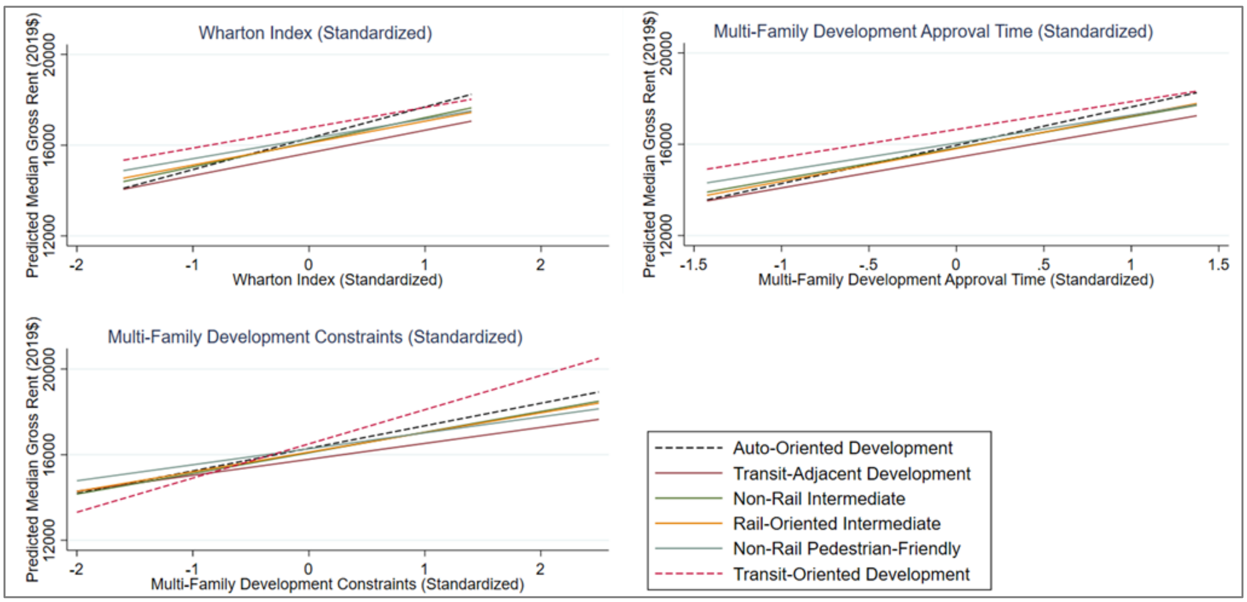

Figure IV-12: Marginal Effects of Median Gross Rent for Neighborhood Types by Land-Use Regulations Measures
Note: Full models in Table VII-1.

Housing advocates and scholars often cite the low supply of housing relative to demand, especially in high-demand areas like transit-oriented development, as a major force behind the current housing affordability crisis. Understandably then, increasing the supply of housing region-wide, and in TODs, in particular, is viewed as a major component in alleviating the housing crisis. A higher ratio of housing units to the total population in a metropolitan area, however, does not seem to be associated with housing costs, except for a positive and significant association with rents in non-rail intermediate development (Housing Units to Population Ratio[4]). The slopes for the cross-level interactions of housing supply and neighborhood types from this model show a negative relationship, but these are based on results that are not statistically significant.

The share of housing units in a metropolitan area that is in TODs is associated with higher rents in rail- and non-rail-proximate pedestrian-friendly neighborhoods (TOD Housing Unit Share). This suggests that rents increase in these neighborhoods as the supply of housing in TODs increases. Moreover, this relationship is strongest in TODs, leading to a steeper slope for this neighborhood type. One explanation for these counterintuitive results is that housing opportunities in TODs are so rare that increasing their supply results in induced demand, leading to higher costs in TODs as well as a spillover effect into neighborhoods that serve as second-best alternatives like rail-oriented intermediate and non-rail pedestrian-friendly development.

On the other hand, a higher share of housing units in neighborhoods that are alternatives to TODs, like rail-oriented intermediate and non-rail pedestrian-friendly development, is associated with a modest moderating effect on housing costs in TODs and their alternatives. First, the share of housing units in non-rail pedestrian-friendly development at the metropolitan level is positively associated with rent at the block group level (Pedestrian-friendly Housing Unit Share Model). However, the interaction terms show that the share of housing units in these neighborhoods also has a moderating effect on rents in the five neighborhood types compared to auto-oriented development. This suggests that while higher shares of non-rail pedestrian-friendly housing units are associated with higher rents, the rent-premium is highest in auto-oriented development while rents in other neighborhood types increase at a slower pace.

[4] Alternative models were estimated using the number of housing units per 100,000 people and different combinations of control variables but these models either did not converge or produced similar results. The ration of housing units to the metropolitan population was preferred since the model includes similar control variables.

Finally, the share of housing units in rail-oriented intermediate development is negatively associated with rents at the block group level, while the interaction with each neighborhood type is positive. Yet, since the overall negative association is larger than the positive interaction terms, the share of housing units in rail-oriented intermediate development is associated with overall lower housing costs in TODs, as well as in their rail and non-rail alternatives, relative to costs in auto-oriented development. These results suggest that the rent premiums that are associated with TODs are expected to be smaller in metropolitan areas that have a higher share of housing units in non-rail pedestrian-friendly neighborhoods and especially in rail-oriented intermediate development. Hence, the supply of housing in rail-oriented intermediate development, and to a lesser extent, also non-rail pedestrian-friendly neighborhoods seems to be associated with lower rents in TODs and other rail-proximate neighborhoods, suggesting that they allow parsing the demand for accessibility from the demand for pedestrian-friendly environments.

Overall, the results in this section support the arguments made in Hypothesis 2. As expected, TODs are the neighborhood type with the highest rents while rents in other transit-rich neighborhoods are associated, to a large degree, with their transportation benefits. Moreover, restrictive land-use regulations are associated with higher housing costs in high-demand neighborhoods, while the supply of housing units in neighborhoods that are alternatives to TODs moderates, and even decreases, housing costs in TODs. These results imply that a larger housing supply in non-rail pedestrian-friendly development and rail-oriented intermediate development, which have lower rents than TODs, reduces the demand for housing in TODs by allowing households to locate in the type of neighborhood that better meets their needs and preferences.

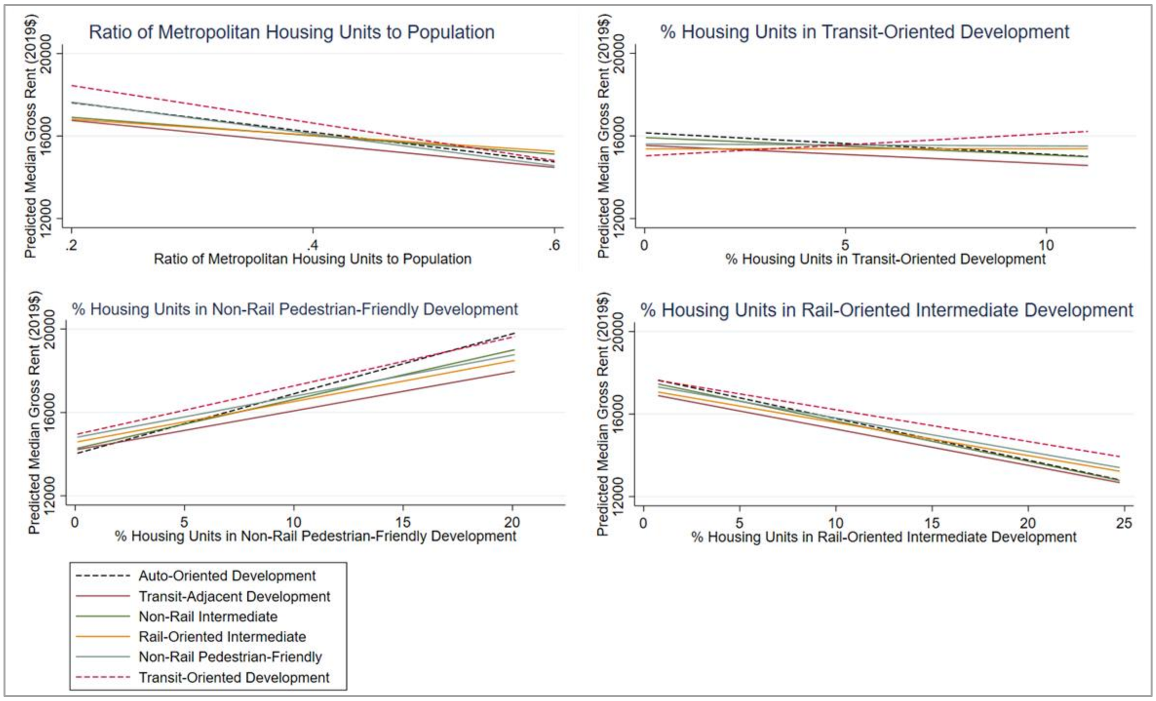

Figure IV-13: Marginal Effects of Median Gross Rent for Neighborhood Type by Housing-Supply Measures; Dependent variable: Annual Median Gross Rent (2019$)

Table IV-13: Housing Supply Models; Dependent variable: Annual Median Gross Rent (2019$)

	Housing Unit to Population Ratio	TOD Housing Unit Share	Pedestrian-Friendly Housing Unit Share	Rail Intermediate Housing Unit Share
VARIABLES	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)
% Housing Units (Reference: Auto-oriented)	-7,176.998	-103.478	287.924***	-201.331***
	(5,095.830)	(113.471)	(79.836)	(67.536)
Transit-adjacent	1,482.471	15.565	-100.499***	25.767*
	(2,213.178)	(27.532)	(24.984)	(14.276)
Non-rail intermediate	2,722.712***	18.935*	-51.575***	6.631
	(898.640)	(11.071)	(8.755)	(5.756)
Rail-oriented intermediate	3,293.586*	103.917***	-92.640***	41.450***
	(1,911.621)	(18.170)	(19.554)	(8.611)
Non-rail pedestrian-friendly	-526.087	93.537***	-90.172***	38.595***
	(1,342.823)	(16.929)	(13.024)	(8.469)
Transit-oriented	-1,915.409	210.671***	-54.120**	47.653***
	(2,228.457)	(25.523)	(23.035)	(11.018)
Observations	52,573	51,959	52,573	52,573
Number of groups	23	22	22	23

*** p<0.01, ** p<0.05, * p<0.1
Note: Full Model presented in Table VII-2.

4.2.3. Summary: Housing Costs

This Section examined the factors that are associated with median gross rent in U.S. metropolitan areas both longitudinally and cross-sectionally. Despite differences in the units of analysis and the criteria for the classification of neighborhoods by type between the cross-sectional and longitudinal analyses, the results in the two sub-sections complement each other. The longitudinal analysis shows that, since 1990, rent has been increasing in all neighborhood types relative to rent in auto-oriented development (low-density non-rail). Moreover, the degree of change over time is larger among rail-proximate neighborhoods and those with higher densities. The cross-sectional analysis provides a more nuanced analysis and shows that proximity to a rail station, transit level of service, and a pedestrian-friendly built environment all have a positive relationship with housing rent.

After controlling for transportation characteristics, however, transit-oriented development is the only neighborhood type that is associated with rents that are higher than in auto-oriented neighborhoods. At the same time, other neighborhoods with pedestrian-friendly environments or near a rail station are associated with rents that are lower than in auto-oriented neighborhoods. Specifically, rent in a TOD is expected to be high due to the benefits that are associated with proximity to a rail station and transit job accessibility as well as to the benefits that stem from a pedestrian-friendly environment.

Finally, the availability of housing units in neighborhoods that might serve as second-best alternatives to TODs, such as non-rail pedestrian-friendly and rail-oriented intermediate development, have a moderating effect on rent in other neighborhood types, including in TODs. The longitudinal analysis, however, suggests that this moderating has become weaker over time. On the other hand, an increase over time in the share of housing units in high-density rail neighborhoods weakens the amplifying effect that is associated with the share of housing in these neighborhoods regionwide. These results suggest that increasing the supply of housing units in TODs might eventually lead to an equilibrium in the market, which would moderate the rent-increases that are associated with this neighborhood type.

Overall, the results in this section suggest that the transportation benefits associated with proximity to a rail station are indeed captured in the housing market, leading to higher rents. At the same time, some of the cost-appreciation near a rail station also stems from neighborhood built-environment characteristics rather than rail level of service. In the next sections, I examine how transportation costs vary with distance to a rail station and transportation level service and how the combination of housing and transportation costs shape affordability for different income levels.

4.3. Transportation Costs

The bid-rent theory identifies a potential tradeoff between housing and transportation costs; households may choose to spend more on transportation in order to save on housing (per unit of land). Others may aim to reduce their transportation costs by locating in more accessible, and therefore also more expensive, locations. Within the location affordability framework, an increase in housing costs will not have a negative effect on affordability only if, combined with transportation, costs do not exceed a certain percentage of income, typically set at 45%. Empirical studies on transportation costs and travel behavior, however, suggest that many households near efficient transit may choose to continue using a private vehicle, thus perhaps weakening the tradeoff between housing and transportation costs.

After examining the factors that are associated with rent and estimating the average rent in six types of neighborhoods, in this section I examine how transportation costs vary by neighborhood type. In addition, an analysis is also conducted to test the relationships between the different neighborhood types and the likelihood of owning a private vehicle as well as commuting using transit. However, since the data on transportation costs are already estimates of costs, inferential statistics in this section are kept to a minimum and the focus is mainly on descriptive variations in transportation costs and characteristics among the six neighborhood types.

Table IV-14: Transportation Characteristics by MSA

MSA	Pop. (Mil.)	Annual Median Income (2019$)	Estimated Annual Transp. Costs (2019$)	Transit Job Access.	% of Households with a Car	% Commute by Transit	VRM: Fixed-Guideway (Millions)	VRM: Non-Fixed-Guideway (Millions)
San Jose	1.7	102,888	15,430	N/A	95.2	3.7	5.9	21.3
San Diego	3.1	68,044	13,695	85,054	93.5	3.4	11.2	48.0
Los Angeles	12.5	62,960	13,525	263,754	91.7	5.8	31.3	235.7
Salt Lake City	1.1	65,881	13,502	131,738	94.2	4.0	8.5	12.4
Sacramento	1.8	63,460	13,339	70,789	92.6	3.0	3.9	14.1
San Francisco	3.4	83,533	13,166	238,494	88.3	16.4	65.8	58.6
Seattle	3.2	74,540	13,019	129,149	92.5	9.2	10.4	94.3
Phoenix	3.8	56,727	12,579	N/A	92.9	2.7	2.5	42.6
Dallas	5.4	61,720	12,560	89,801	94.2	2.0	11.0	50.1
Denver	2.5	68,418	12,505	150,732	93.8	4.9	11.4	44.4
Atlanta	4.7	61,465	12,500	53,049	91.6	5.1	22.3	44.8
Houston	5.3	62,920	12,445	144,242	92.6	3.0	2.4	72.4
Austin	1.5	69,106	12,416	118,091	94.2	3.3	0.3	22.2
Portland	1.9	63,507	12,389	124,153	91.1	7.5	8.9	33.2
Charlotte	1.3	63,722	12,325	N/A	91.8	2.7	1.1	19.3
Minneapolis	2.7	72,117	12,135	N/A	91.3	6.2	6.2	55.2
Washington DC	4.9	100,280	11,815	358,953	84.9	21.6	91.5	108.8
Boston	4.3	79,286	11,739	260,467	85.0	15.3	52.5	56.2
St. Louis	2.2	58,359	11,737	88,206	88.5	5.2	6.2	28.6
Miami	5.8	51,918	11,593	85,200	90.6	4.5	14.8	83.1
Chicago	8.7	65,561	11,589	216,371	86.6	14.1	117.7	124.1
Baltimore	2.3	71,128	11,393	152,974	83.8	10.9	10.3	41.3
Philadelphia	5.5	65,251	11,250	230,722	82.9	14.4	47.9	77.2
Pittsburgh	1.7	56,675	11,037	105,282	84.7	9.1	4.7	33.1
Buffalo	0.9	52,309	10,991	93,667	82.9	5.9	0.8	10.0
Cleveland	1.8	53,204	10,901	105,060	86.5	5.9	4.0	22.7
New York	18.8	70,707	10,061	784,528	70.3	32.8	541.9	333.5

Note: MSAs in order of estimated annual transportation costs; Pop. (Mil.): Population (Millions); Transp.: Transportation; Access.: Accessibility.

A household's transportation costs are a function of a combination of household, neighborhood, and metropolitan factors. At the household level, household composition, preferences, and stage in the life cycle affect travel preferences and auto ownership and use. At the neighborhood level, built-environment characteristics like the degree of mixed-use development affect whether a household is able to substitute auto travel with alternative modes like transit, walking, or bicycling. Finally, at the regional level, the job-housing balance, the concentration of employment, and the provision of efficient transit affect the degree to which a household needs to rely on the private vehicle for daily use. Combined, these factors are expected to determine travel behavior in terms of the mode used, the distance traveled, and the frequency of trips, thus allowing to estimate the transportation costs that are associated with a specific household or location (CNT, H+T Index: Methods, 2015).

Transportation costs at the metropolitan level tend to be higher in MSAs with higher incomes and with a larger share of households with at least one private vehicle (Table IV-14). On the other hand, costs are lower in MSAs with a larger average transit job accessibility and, closely related, also the share of households that commute by transit. Similarly, higher levels of rail and bus service in terms of fixed- (rail) and non-fixed (bus) guideway vehicle revenue miles (VRM), which serve as a proxy for rail and bus service, respectively, also seem to be associated with lower transportation costs. However, some metropolitan areas that offer relatively high levels of transit service, like Los Angeles and San Francisco, still exhibit high transportation costs. Thus, the relationship between transit level of service and transportation costs might be mediated by other factors like the dispersion of employment across a metropolitan area or personal preferences for the private vehicle.

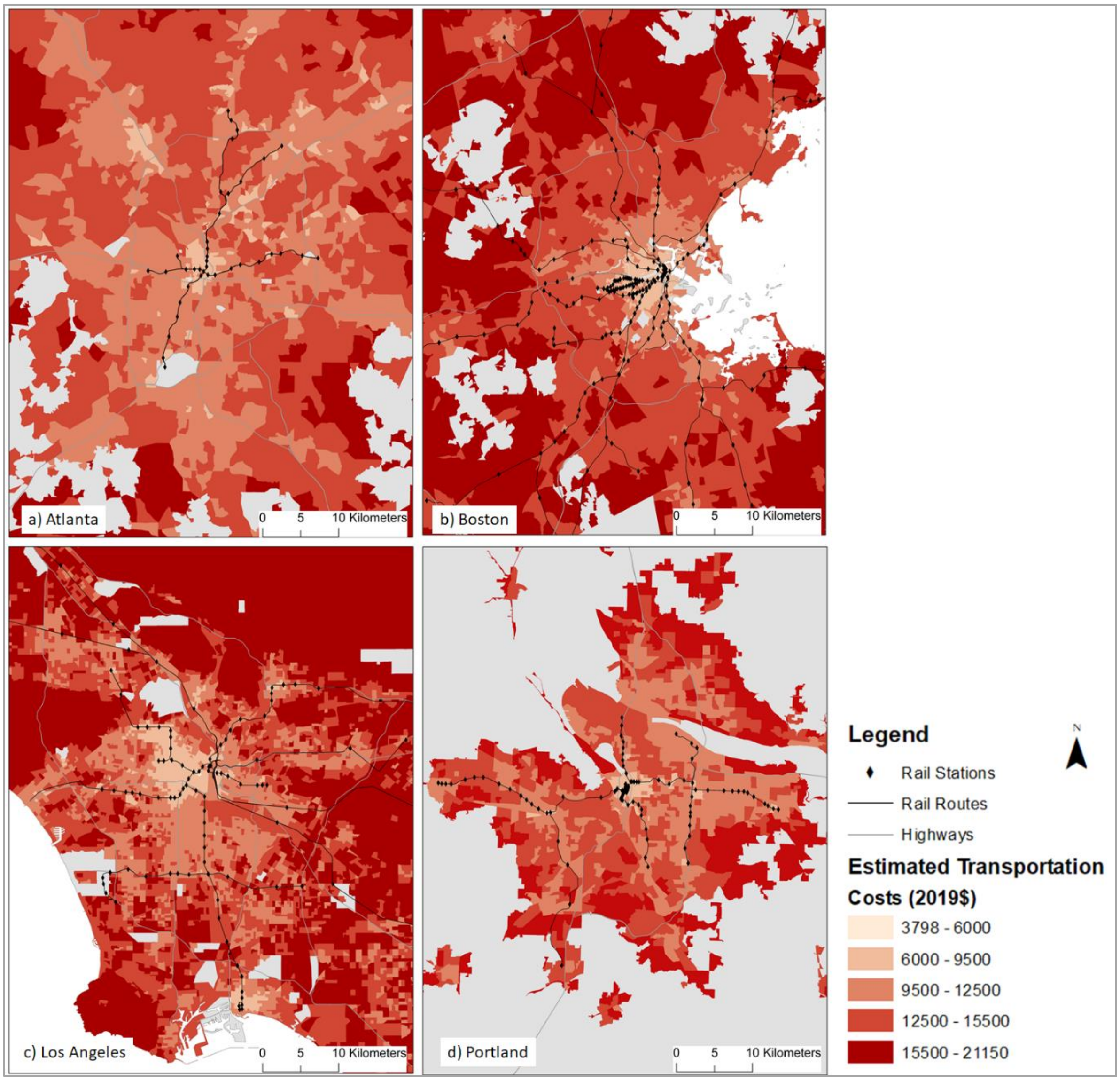

Figure IV-14: Estimated Average Transportation Costs (2019$) in Four Metropolitan Areas

Within a metropolitan area, transportation costs are lower closer to employment centers, especially around the MSA's CBD (Figure IV-14). In more polycentric MSAs, like Atlanta and Los Angeles, employment is more spread out across the metropolitan area and lower transportation costs extend farther out from the CBD, perhaps due to shorter commutes. In the more monocentric Boston region, on the other hand, transportation costs are lower close to the CBD and increase with distance from the center. In addition, transportation costs also tend to be lower along rail lines, which suggests that households that live close to a rail station can reduce their transportation costs by substituting private vehicle use with transit.

The effect of rail service on transportation costs, however, might be stronger near heavy and light rail service while commuter rail, like the routes extending outward to more suburban and ex-urban locations in the Boston MSA, have a weaker effect on costs. One explanation for the differential effect of rail mode on transportation costs is the level of service that is associated with each mode; heavy and light rail services tend to be more frequent, and perhaps also travel faster, than commuter rail trains, which translates into better level of service that is provided by heavy and light rail.

4.3.1. Transportation Costs by Neighborhood Type

The previous sections identified that transportation factors, and especially transit job accessibility, provide a benefit that is capitalized into the housing market. Such a tradeoff may exist if the transportation characteristics of a neighborhood allow reducing transport costs (Hypothesis 3). Indeed, among the six neighborhood types, transportation costs tend to be lower in rail-oriented and pedestrian-friendly neighborhoods and higher in lower-density auto-oriented neighborhoods (Figure IV-15; Table IV-15). An Analysis of Variance (ANOVA) test supports the argument that the difference in average estimated transportation costs between each pair of neighborhood types is statistically significant at the 99% confidence level (Table VII-4). Moreover, not only are the average and median transportation costs in rail-oriented and pedestrian-friendly neighborhoods lower than in more suburban neighborhoods, but their range is also at the lower distribution of costs.

The major factors behind the differences in transportation costs seem to be the lower shares of car ownership and the higher share of commute by transit in rail-oriented and pedestrian-friendly neighborhoods, which are afforded by the higher levels of transit job accessibility that characterizes these neighborhoods (Table IV-15). Suburban neighborhoods, on the other hand, are oriented toward the private vehicle and are characterized by lower levels of transit job accessibility, including near rail stations. As a result, they are characterized by higher levels of car ownership and low levels of commute by transit, which translate into higher transportation costs.

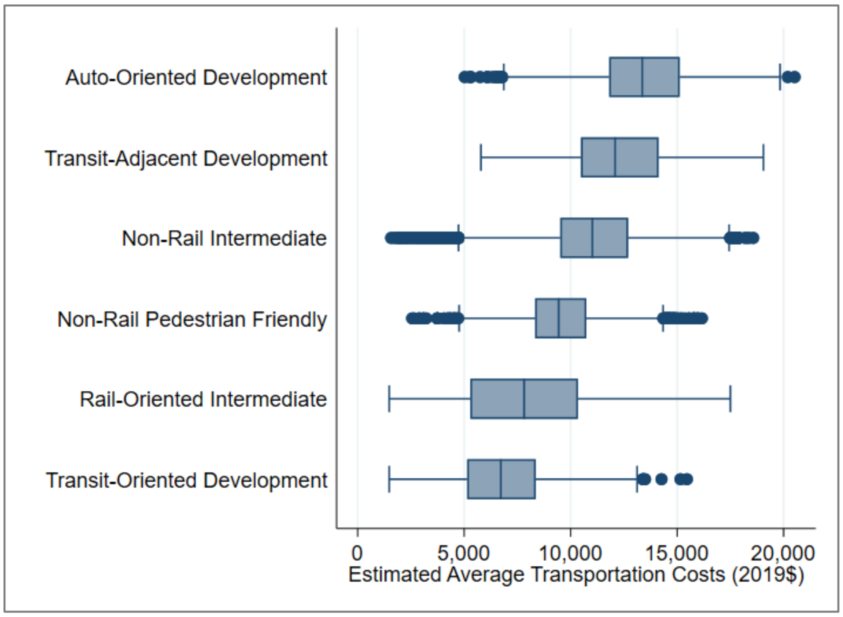

Figure IV-15: Estimated Transportation Costs by Neighborhood Type

Table IV-15: Estimated Transportation Costs and Characteristics by Neighborhood Type

Neighborhood Type	Distance to CBD (KM)	Transportation Costs (2019$)	Transit Job Accessibility	% with a Private Vehicle	% Commute by Private Vehicle	% Commute by Transit	% Commute by Rail
Transit-oriented	9.0	6,738	1,374,969	51.8	33.0	44.6	31.5
Non-rail pedestrian-friendly	12.7	9,508	474,768	76.6	62.6	21.4	6.6
Rail-oriented intermediate	14.0	8,002	1,146,425	58.8	43.5	40.6	27.7
Non-rail intermediate	19.9	11,127	288,639	84.3	75.2	14.5	4.6
Transit-adjacent	23.7	12,243	235,843	88.6	76.1	13.9	4.4
Auto-oriented	31.4	13,438	71,844	93.7	86.9	5.0	0.9

Still, even in neighborhoods with high levels of transit accessibility, such as TODs and rail-oriented intermediate development, more than 50% of households own a private vehicle, and just over 40% of households commute by transit (Table IV-15). This suggests that a considerable share of the households living near rail stations do not, or cannot, fully substitute private vehicle ownership and use with transit. To the extent that the higher housing costs near rail stations reflect accessibility gains that allow reducing transportation costs, as the bid-rent theory suggests, low levels of substitution between car and transit implies that for many households the higher housing costs near rail might be larger than their savings in terms of transportation costs. Consequently, neighborhoods near rail stations that provide high levels of accessibility may be less affordable to households that choose not to, or cannot, fully substitute their car use with transit use.

To further test the relationships between neighborhood types and transportation characteristics on the one hand and transportation outcomes, on the other hand, a set of multilevel regression models were estimated on transportation costs, auto ownership, and transit use (Table IV-16). Since the transportation costs data are already estimates, the regression model that is fitted to illustrate the relationship between transportation costs and neighborhood types. The regression models support the argument that transit-rich neighborhoods have lower transportation costs than more auto-oriented neighborhoods and this relationship is a product of lower levels of auto ownership and higher levels of transit and rail use.

Metropolitan areas that provide more extensive rail service and central neighborhoods, those that are closer to a rail station, and transit-rich neighborhoods are associated with lower auto ownership, higher transit use, and therefore also lower estimated transportation costs. At the metropolitan level, higher housing-unit densities and levels of rail service (in terms of fixed-guideway vehicle revenue miles) are associated with lower estimated transportation costs and auto ownership and higher shares of transit and rail use. The variables at the neighborhood level follow similar trends. As assumed by the bid-rent theory, distance from the CBD is associated with higher transportation costs, in part due to higher levels of car ownership and lower levels of commute by transit. Similarly, proximity to a rail station and transit job accessibility are associated with lower transportation costs and auto ownership, in part due to higher levels of commute by transit. These outcomes suggest that enabling households to substitute auto ownership and use through transit can lead to lower transportation costs.

Even after accounting for transportation characteristics, transit-rich and walkable neighborhoods are still associated with lower transportation costs and auto ownership and higher shares of commute by transit and rail, compared to auto-oriented development. The larger effect sizes associated with transit-oriented development and rail-oriented intermediate development compared to non-rail pedestrian-friendly development suggests that proximity to rail is an important component in enabling households to substitute auto ownership and use with transit use. Interestingly, while non-rail pedestrian-friendly and non-rail intermediate development are associated with lower transportation costs and auto ownership than auto-oriented development, they are also associated with lower shares of individuals commuting by rail. These outcomes suggest that in non-rail pedestrian-friendly and non-rail intermediate development households that rely on transit mainly use bus service. On the other hand, households in auto-oriented development that use transit might rely more on rail service, perhaps since bus might not extend to more suburban locations and because rail provides good access to the CBD.

Table IV-16: Transportation Costs Models

VARIABLES	Estimated Average Annual Transportation Costs Coef. (Std Err)	% of households with a Private Vehicle Coef. (Std Err)	% of Individuals Commuting by Transit Coef. (Std Err)	% of Individuals Commuting by rail Coef. (Std Err)
Block-Group Level				
% Black	-9.679***	-0.149***	0.140***	0.016***
	(0.212)	(0.002)	(0.002)	(0.002)
% Hispanic	-6.768***	-0.048***	0.008***	-0.018***
	(0.270)	(0.002)	(0.003)	(0.002)
Median Household Income (1000s)	22.724***	0.084***	-0.012***	-0.011***
	(0.144)	(0.001)	(0.001)	(0.001)
% Age 25-39	-26.556***	0.155***	0.008*	0.029***
	(0.488)	(0.004)	(0.005)	(0.004)
Average Household Size	228.569***	1.794***	0.445***	0.121*
	(8.881)	(0.080)	(0.081)	(0.065)
% Multi-family Housing Units	-21.637***	-0.095***	0.014***	-0.013***
	(0.209)	(0.002)	(0.002)	(0.002)
Distance to Highway Ramp (Km)	47.669***	-0.069***	0.158***	0.190***
	(2.505)	(0.023)	(0.023)	(0.018)
Distance to CBD (Km)	18.240***	0.026***	-0.132***	-0.027***
	(0.315)	(0.003)	(0.003)	(0.002)
Distance to Rail (Km)	0.907	-0.046***	0.061***	0.050***
	(0.607)	(0.008)	(0.006)	(0.004)
Neighborhood Type (Reference: Auto-oriented)				
Transit-adjacent	-294.010***	0.045	2.945***	0.334*
	(25.936)	(0.234)	(0.238)	(0.188)
Non-rail intermediate	-645.267***	-0.582***	1.686***	-0.902***
	(11.373)	(0.102)	(0.104)	(0.083)
Rail-oriented intermediate	-779.239***	-4.923***	7.926***	4.972***
	(20.504)	(0.185)	(0.188)	(0.149)
Non-rail pedestrian-friendly	-1,242.292***	-3.353***	3.853***	-2.768***
	(19.328)	(0.174)	(0.177)	(0.140)
Transit-oriented	-1,339.646***	-9.257***	9.363***	5.205***
	(27.178)	(0.245)	(0.249)	(0.198)
Job Accessibility (1000s)	-1.651***	-0.014***	0.011***	0.014***
	(0.014)	(0.0001)	(0.0001)	(0.0001)
Metropolitan level				
Population Density	-9.072***	-0.087***	0.073***	0.059***
	(0.170)	(0.002)	(0.002)	(0.001)
Fixed-Guideway Vehicle Revenue Miles (Millions)	-1.046	-0.010*	0.032***	0.016***
	(1.433)	(0.005)	(0.006)	(0.004)
Constant	11,492.136***	84.863***	1.938**	-1.355***
	(173.904)	(0.682)	(0.760)	(0.493)
Observations	63,905	63,905	63,899	63,899
Number of groups	23	23	23	23

Wald test	396387***	143951***	90658***	93753***
Linear Regression test	21024***	2811***	4742***	3136***

*** p<0.01, ** p<0.05, * p<0.1

4.3.2. Summary: Transportation Costs

The results in this section support Hypothesis 3, indicating that transportation costs are lower in rail-proximate and pedestrian-friendly neighborhoods compared to lower-density auto-oriented neighborhoods. These outcomes are due, in part, to transportation costs being lower in more central locations, and especially in neighborhoods that are served by a rail station. These neighborhoods enjoy higher levels of transit job accessibility, which allows the households living in them to substitute private vehicle ownership and use with transit use. The levels of transportation costs by neighborhood type, together with the findings on housing costs, suggests that a tradeoff between housing and transportation costs might exist. To examine the equity implications that are associated with the housing-transportation cost relationship, the next sections provide an analysis of housing, transportation, and location affordability.

4.4. Housing, Transportation, and Location Affordability in U.S. Metropolitan Areas

The analysis up until this point has focused on the costs of housing and transportation and the factors associated with them. This analysis shows that housing costs tend to be higher in areas with better transportation services in terms of transit job accessibility, distance to a rail station, and in neighborhoods near a rail station. As expected, transportation costs show the opposite relationships, with lower transportation costs in transit-rich areas. A question remains, however, whether the transportation costs near rail are sufficiently low to compensate for the higher housing costs in accessible locations and to make these locations affordable to households from different income groups.

In this section, I provide an analysis of housing, transportation, and location affordability across MSAs, neighborhood types, and income levels. The underlying question in this section asks how are the various factors that are associated with rent and transportation costs translate into housing and transportation cost burdens. Building on this, I also examine the implications of these outcomes to the affordability of different neighborhood types to lower-income households. The section begins with a longitudinal analysis of affordability, followed by a brief overview of affordability between MSAs and neighborhood types. The section concludes with a cross-sectional analysis of the affordability of different types of neighborhoods to households from different income levels. I find that most neighborhoods tend to be affordable to a household earning 80% or more of the area median income but not to households earning 50% or less of the area median income. The factors that affect affordability, however, vary between MSAs and neighborhood types.

The focus on neighborhood-level affordability relative to area median income produces considerably lower cost burdens than the ones found in studies that use a household-level affordability measure (e.g., Renne, Tolford, Hamidi, & Ewing, 2016). This might be because households might choose to live in higher-cost neighborhoods in order to enjoy non-housing or transportation benefits like access to schools or green spaces. Among low-income households, higher household-level cost burdens may stem from fewer housing options in affordable locations. The focus on neighborhood-level affordability, on the other hand, allows asking whether a household with a certain level of income can afford to live in a specific location, regardless of whether or not a household decides to locate there.

4.4.1. A Longitudinal Analysis of Housing Affordability

In this section, I examine the change in housing costs and affordability between 1980 and 2017 in different MSAs, neighborhood types, and for households at four income levels. The analysis focuses on changes over time that may be associated with change in housing affordability. These changes include trends in rent, income, and housing supply at the metropolitan level as well as neighborhood-level factors. The analysis shows that housing costs have become less affordable over time, especially to lower-income households. Moreover, while the housing cost burden increased in all neighborhood types, the effect is stronger in higher-density rail neighborhoods. As a result, rail-proximate neighborhoods have become less affordable to lower-income households.

The current housing affordability crisis felt in many metropolitan areas across the United States is first and foremost a result of diverging trends in housing costs and income (Figure IV-16). Between 1980 and 2017, median gross rent in the MSAs in this study increased by thirty-seven percent while income increased by just fourteen percent. This represents a twenty-three percent gap between the change in rent and income. While these trends have been in play at least since the 1980s, they have intensified since 2000. MSAs across the distribution of housing cost burden in 2017 experienced similar increases in the housing cost burden between 2000 and 2017. In MSAs with middle and high housing cost burdens in 2017, housing cost burden seems to be associated with a sharp increase in median gross rent between 2000 and 2017 alongside mostly stagnant incomes. On the other hand, MSAs at the lower end of the housing cost burden distribution experienced more moderate increases in rent alongside decreasing median incomes.

MSAs that experienced sharp decreases in income tend to have also experienced larger increases in the average housing cost burden between 2000 and 2017 but this relationship does not seem to explain the changes in rent and affordability (Figure IV-16). As can be expected, the MSAs that experienced the largest decreases in the share of census tracts that are affordable to the median income household and especially to the 50% of median-income households also had a higher housing cost burden in 2017.

MSAs that experienced larger percent-increases in the number of housing units also experienced larger percent-increases in rent, though the majority of MSAs experienced only moderate increases in the number of housing units (Figure IV-16). While these increases were larger than the increase in the number of households in an MSA, they may still represent a factor contributing to increases in the housing cost burden. Specifically, the low rates of housing-unit change might represent the constraints on housing supply, which is associated with faster increases in rents. Indeed, MSAs that experienced larger increases in housing units, like Charlotte, Austin, Atlanta, and Phoenix, also experienced slower increases, and even negative changes, in median gross rent between 2000 and 2017.

A closer look at selected MSAs shows that the rate of change in rent, income, and housing affordability is not linear and varies between MSAs (Figure IV-17). At the higher end of the rent-change distribution, MSAs like San Francisco and Washington D.C. experienced sharp rent increases between 1980 and 1990, followed by a decrease in rent between 1990 and 2000. However, since 2000, rents have been increasing rapidly. Los Angeles and Boston experienced a similar trend in rent-change, though the increase in rent in these MSAs has been slower since 2012. Except for Washington D.C., incomes in these MSAs changed at a much slower pace, which can explain part of these MSAs' housing affordability issues. The different trends in rent and income are the sharpest in Los Angeles, which experienced a decrease in real income between 1990 and 2012. Together with the increase in rent over time, this may explain why Los Angeles is experiencing one of the more severe housing affordability problems in the nation.

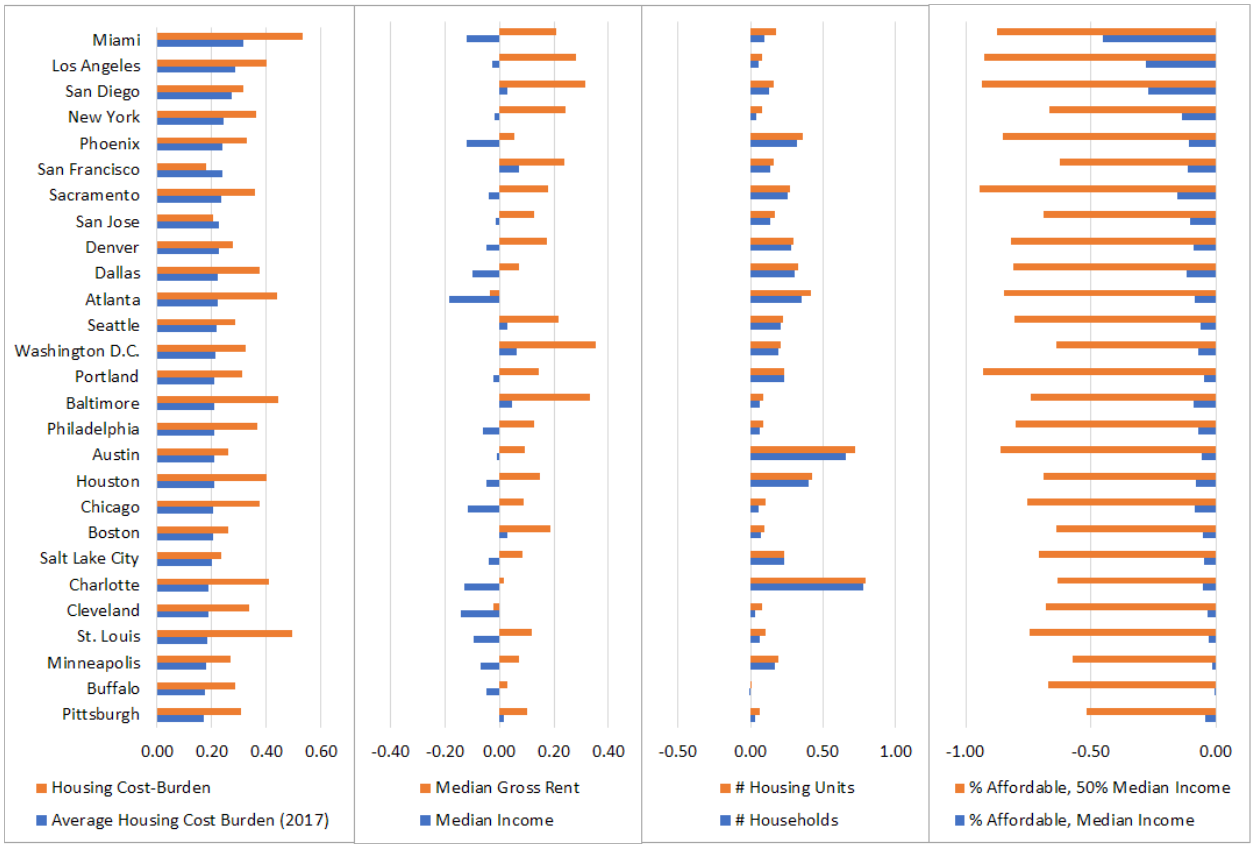

Figure IV-16: % Change in Affordability, Cost, and Housing Characteristics between 2000-2017

Notes: MSAs in order of declining % change in housing cost burden. All figures report on % change between 2000 and 2017 except for Average Cost burden (2017), which reports information for 2017.

Other MSAs experienced slower increases in rent, and the increase in housing cost burden is associated with a decrease in income. While this process may explain the housing affordability problems that are experienced in MSAs like Minneapolis, Pittsburgh, and Portland, its most stark example is Miami. Between 1980 and 2000, the housing cost burden remained fairly stable and even experienced a slight decrease due to an increase in income that countered a similar increase in rents. However, while rents in Miami did not increase at a faster rate than in other MSAs since 2000, real income in Miami actually decreased between 2000 and 2017. The result is a rapid increase in housing cost burden and one of the worst housing affordability problems in the nation.

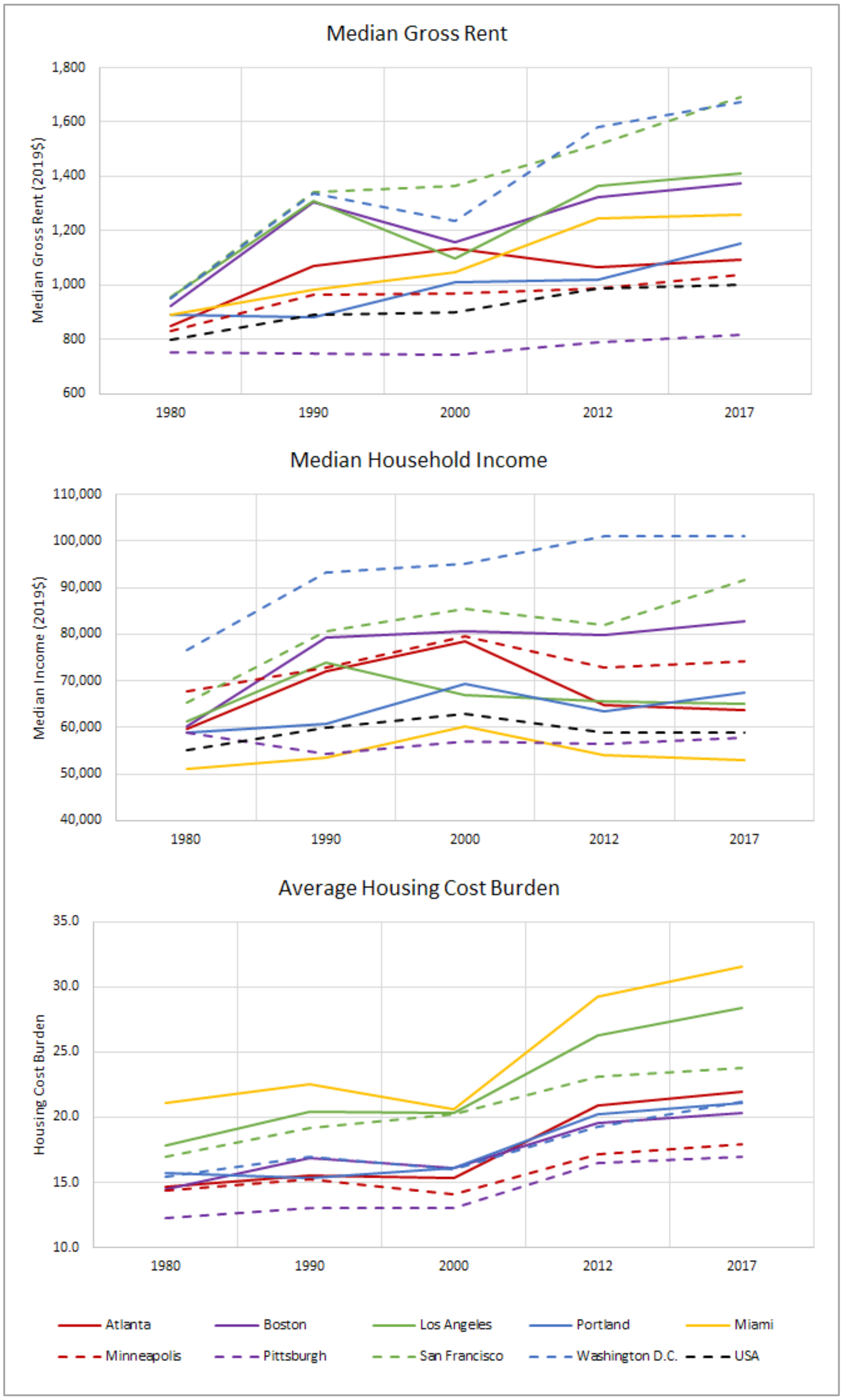

Figure IV-17: Trends in Income, Housing Costs, and Affordability in Select Metropolitan Areas, 1980-2017

Despite evidence suggesting that stagnant incomes may have contributed to the housing affordability crisis, the majority of research has focused on how housing-related factors impact housing costs and affordability. Most notably, the unaffordability of housing is explained as a housing shortage problem, mainly due to restrictive zoning practices that prevent the development of an adequate amount of housing units. The analysis in this section suggests that housing shortage might indeed explain the current housing affordability crisis, but only in a subset of MSAs (Figure IV-18). These MSAs are somewhat similar to those that Gyourko et al. (2013) referred to as superstar cities, as they are in high demand but experience slow increases in housing units. Specifically, MSAs like San Francisco, San Jose, and New York in the 1980-2017 period and Los Aneles, San Diego, and Washington D.C. in the 2000-2017 period experienced large increases in house values alongside a slow change in housing units, suggesting that a housing shortage is an important factor in the house value change.

Similar trends are found for the relationship between housing unit change and rent change, although the specific MSAs in the top left, housing shortage-high rent, quadrant are somewhat different. This suggests that in some MSAs, change in housing units may have a different relationship with house value and with rent. While these MSAs are commonly associated with high housing cost burdens, their appearance in one time period or the other might help identify when their housing affordability problems began. MSAs like San Jose and San Francisco are mainly present in the 1980-2017 period but not in the 2000-2017 period, suggesting that their affordability problems are associated with dynamics in their housing market in the 1980s and 1990s. On the other hand, Los Angeles, Washington D.C., and Baltimore are only present in the second period, suggesting that the high rents in these MSAs are mainly due to a housing shortage that originated in the 2000s.

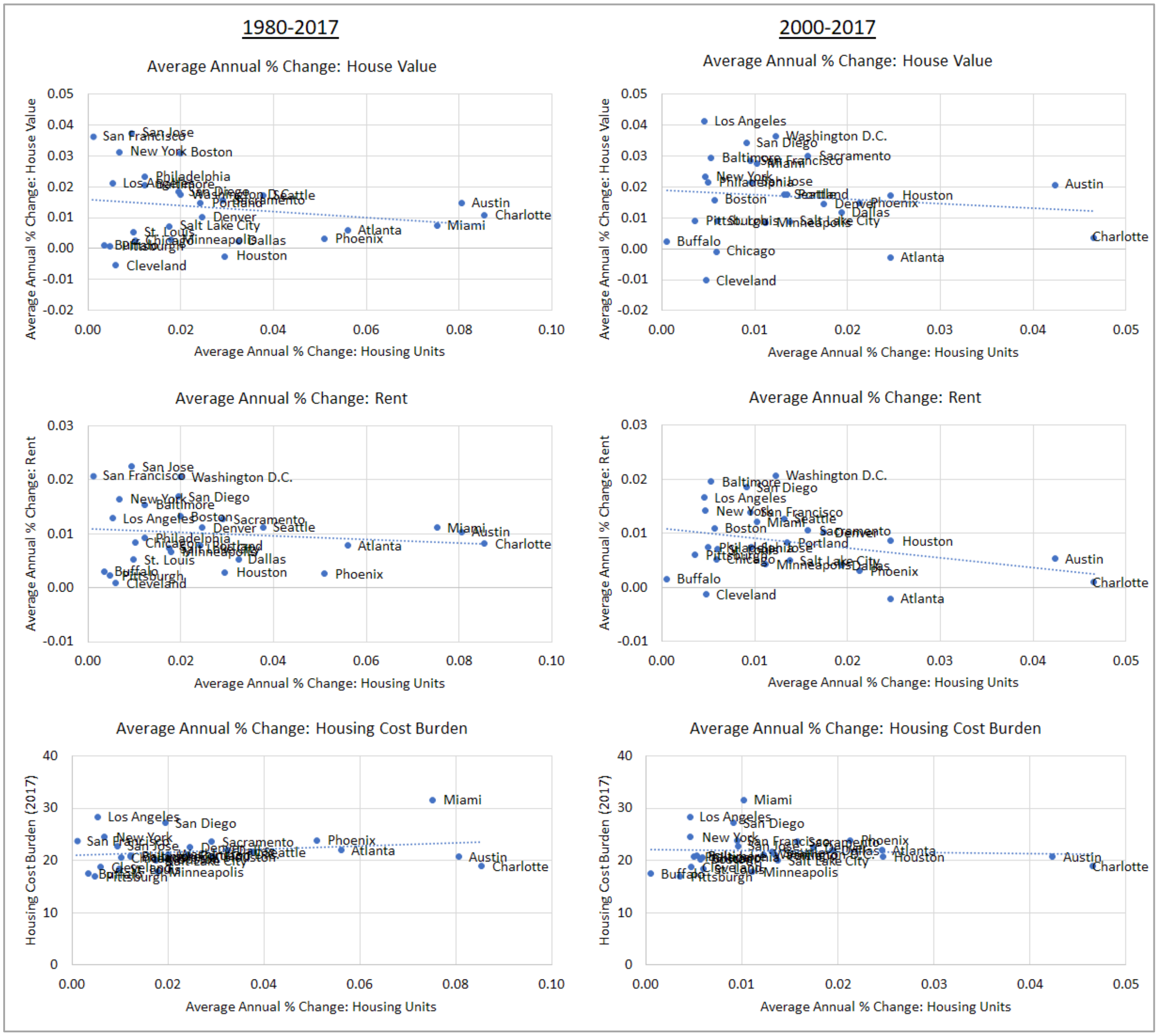

Figure IV-18: Average Annual Percent Change in House Value, Rent, and Cost burden by Change in Housing Units, 1980-2017
Note: Trend lines are only illustrative.

Unlike its relationship with house value and rent, change in housing units between 1980 and 2017 seems to have a positive relationship with the housing cost burden in 2017. This relationship, however, seems to be influenced by Miami, which had a high housing cost burden in 2017 despite experiencing a relatively large increase in the share of housing units. On the other hand, the rate of housing-unit change in Miami slowed down between 2000 and 2017, which can explain the rapid increase in rent during the same time period (Figure IV-18). The other MSAs with small housing-unit change and high housing cost burdens are also the MSAs with the strongest negative relationship between housing-unit change and house value and rent. This suggests that among these MSAs, housing affordability may be, in part, a result of the slow supply of housing regionwide.

Within an MSA, a higher share of census tracts in all six neighborhood types had housing costs that were affordable to higher-income households than to lower-income households (Figure IV-19). Housing affordability, however, has been decreasing over time in all neighborhood types, even for households earning the area median income. While this decrease in affordability began in the 1980s and 1990s, affordability has been decreasing more rapidly since 2000. This is mainly due to a slower increase in incomes since 2000 alongside a rapid increase in rents during the same time period (Figure IV-20).

Households earning 50% of the area median income seem to be the income level that has been hit the worst from the decrease in housing affordability. And the decrease in the share of census tracts that are affordable to this income level was mainly felt in medium- and high-density rail and non-rail neighborhoods, which tend to be the more transit-rich neighborhoods. As a result, by 2017, less than 20% of neighborhoods of all types had housing costs that were affordable to a household earning 50% of area median income.

For households earning 30% of the area median income—the lowest income level in the analysis—higher-density rail and non-rail neighborhoods were the neighborhood types with the highest share of affordable neighborhoods in 1980. By 2017, however, housing affordability for this income level decreased in all neighborhood types to the extent that only about 2-percent of neighborhoods have housing costs that are affordable to extremely low-income households.

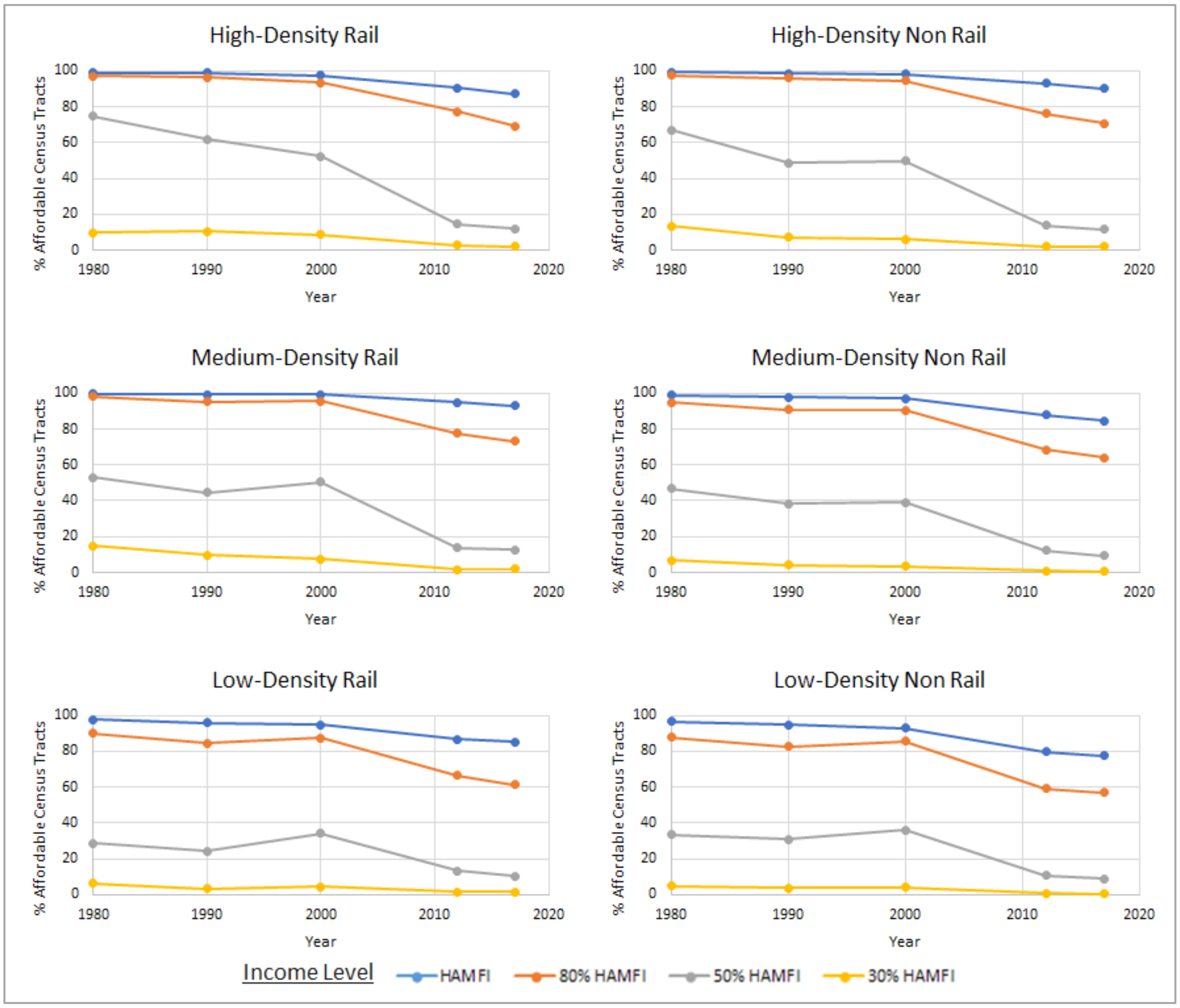

Figure IV-19: Change in the Share of Affordable (Housing) Census Tracts by Neighborhood Type and Income Level, 1980-2017

Note: HAMFI: HUD Area Median Family Income.

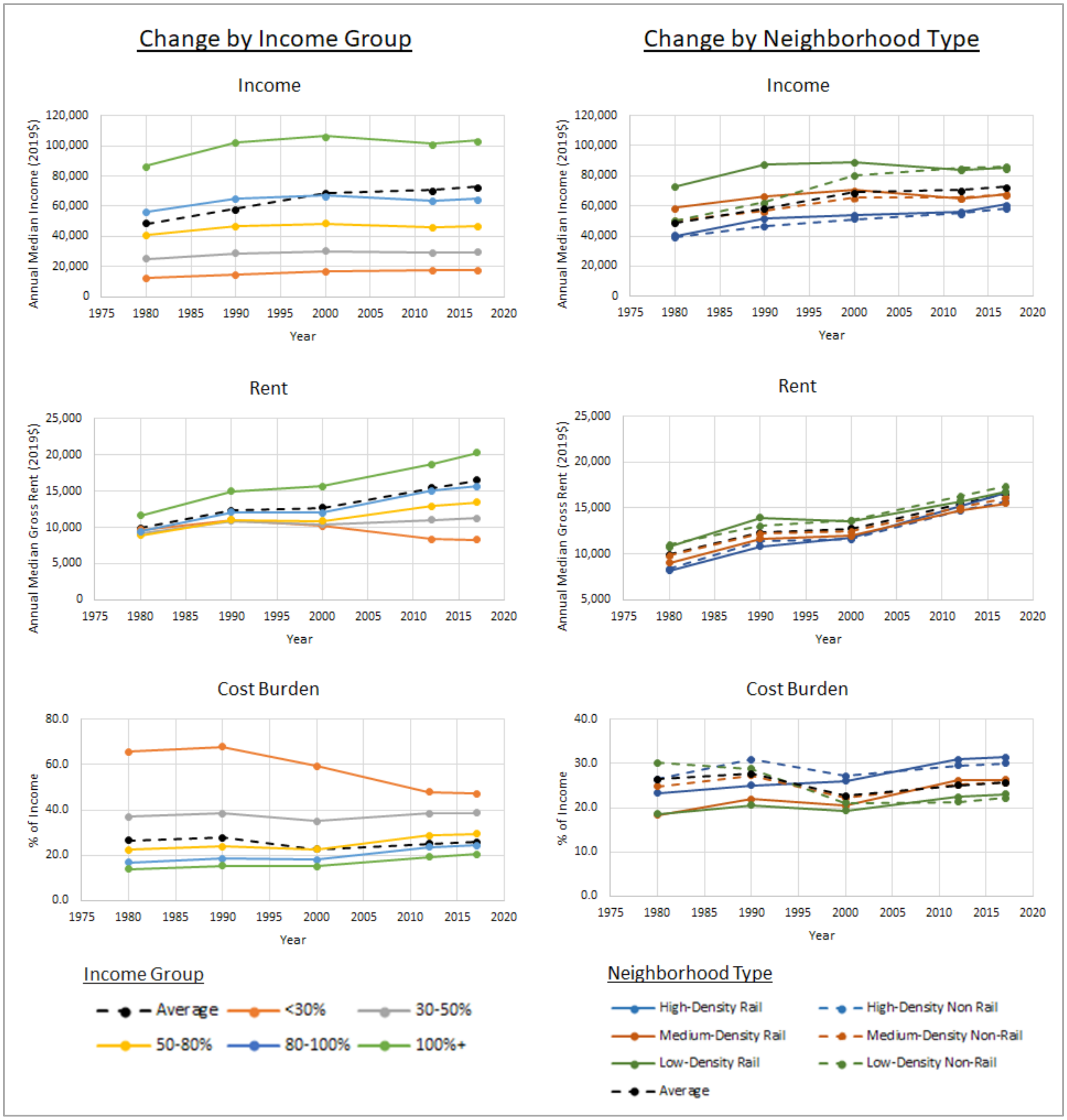

Figure IV-20: Change in Income, Rent, and Housing Cost burden within Income Groups and Neighborhood Types, 1980-2017

Note: A census tract may move between neighborhood types and income groups over time. Cost burden for the income group earning less than 30% of area median income is calculated relative to 20% of area median income; cost burden for the income group earning between 30-50% of area median income is calculated relative to 30% of area median income; cost burden for the income group earning between 50-80% of area median income is calculated relative to 50% of area median income; cost burden for the income group earning between 80-100% of area median income is calculated relative to 80% of area median income; cost burden for the income group earning 100%+ of area median income is calculated relative to area median income.

The decrease in affordability between 1980 and 2017 is, to a large degree, a function of stagnant and even decreasing incomes in many metropolitan areas (Figure IV-17) alongside a considerable increase in median gross rent in each of the six neighborhood types (Figure IV-20). Most notably, rent in high-density rail doubled between 1980 and 2017, making it the neighborhood type (together with low-density rail) with the second-highest rent among the six neighborhood types. The rapid increase in rent in all neighborhood types, and especially in high-density rail neighborhoods—the neighborhood type that is most associated with high-demand transit-rich development—can explain much of the housing cost burden many U.S. households are experiencing.

High-density rail and non-rail neighborhoods are also less affordable to the households that live in them, at least in terms of housing costs (Figure IV-20). Again, this is because median income in these neighborhoods has increased at a lower rate than rent. Medium- and lower-density neighborhoods experienced a smaller change in housing cost burden over the study period, mainly due to a larger increase in incomes. These results suggest that medium and low-density neighborhoods have become more affordable to their residents than higher-density neighborhoods, either because higher-income residents have moved in or because the income of their original residents has increased.

Among different income groups, housing is least affordable in census tracts in which the median income is less than 30% of the area median income (Figure IV-20). Yet, the housing cost burden for this income group also decreased markedly between 1980 and 2017. This decrease in housing cost burden is due to a small increase in the income in extremely low-income neighborhoods alongside a decrease in rent, especially between 1990 and 2012. At the same time, the other income groups experienced a decrease in housing affordability, mainly due to increasing rents, especially at the higher end of the income distribution. However, only neighborhoods with median income equal to or below 50% of area median income were housing cost burdened in 2017. These outcomes suggest that the ability to find housing that is affordable is mainly a problem for lower-income groups.

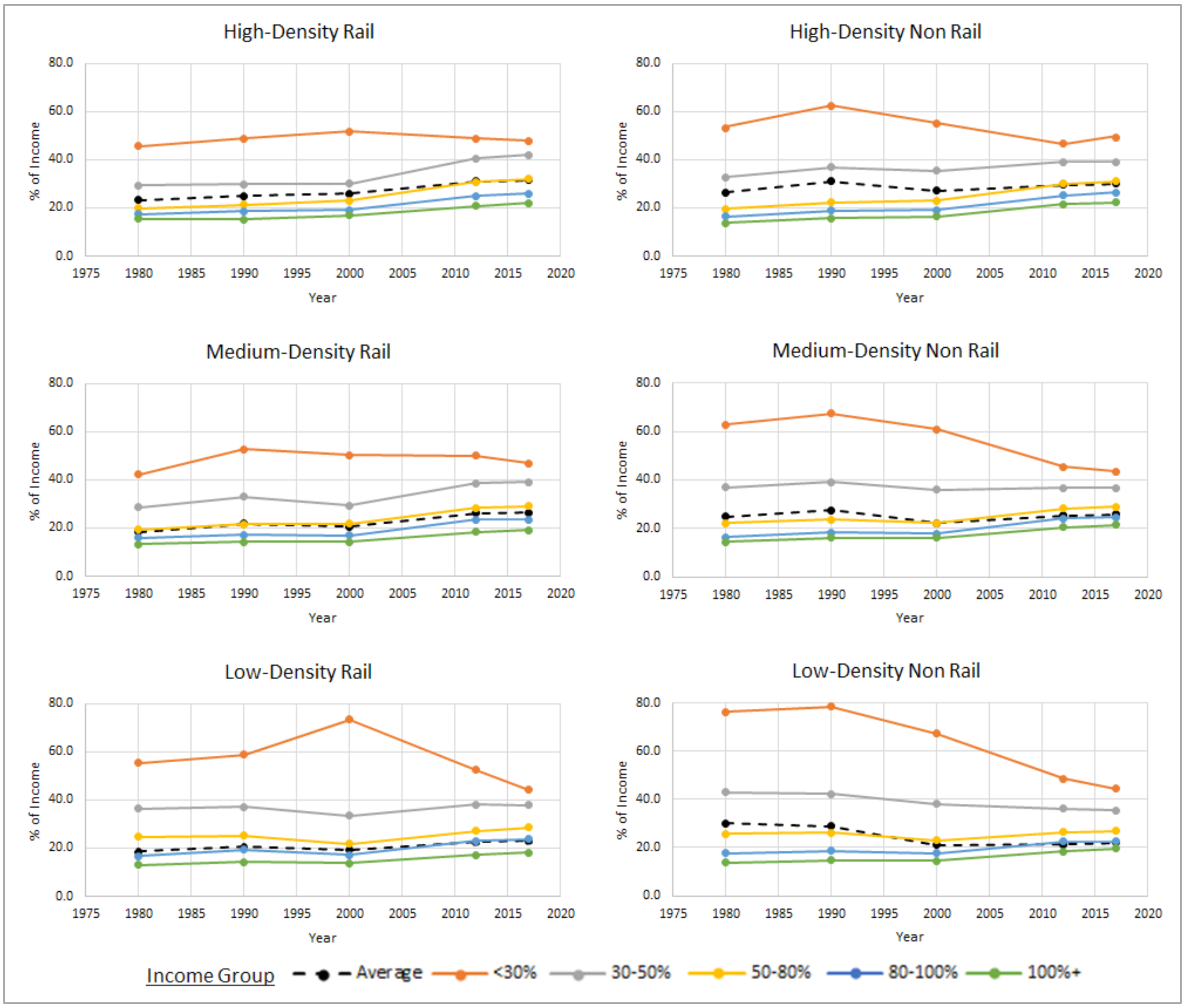

Figure IV-21: Housing Cost burden Change by Neighborhood Type and Income Group, 1980-2017

Note: Cost burden for the income group earning less than 30% of area median income is calculated relative to 20% of area median income; cost burden for the income group earning between 30-50% of area median income is calculated relative to 30% of area median income; cost burden for the income group earning between 50-80% of area median income is calculated relative to 50% of area median income; cost burden for the income group earning between 80-100% of area median income is calculated relative to 80% of area median income; cost burden for the income group earning 100%+ of area median income is calculated relative to area median income.

Finally, the housing cost burden in extremely low-income neighborhoods decreased between 1980 and 2017 in all neighborhood types (Figure IV-21). In neighborhoods with very low-incomes between 30-50% of area median income, however, housing cost burden increased between 1980 and 2017 in medium- and high-density rail neighborhoods and in high-density non-rail neighborhoods. One explanation for the different trends in extremely- and in very low-income neighborhoods is that rent in the latter neighborhoods increased at a higher rate than income compared with changes in extremely-low neighborhoods. Housing cost burden in medium- and high-density rail and non-rail neighborhoods also increased in higher-income neighborhoods. However, incomes in these neighborhoods are still high enough to render these neighborhoods affordable to their income level.

Overall, the results in this section indicate that between 1980 and 2017, housing cost burden increased in all metropolitan areas in the sample and in all neighborhood types considers. An increase in housing cost burden was more notable in MSAs and neighborhood types that experienced a large increase in rent alongside a small change in income. One explanation for the large increase in rent is the low rates of housing supply in most of the MSAs in the sample. The result is a decrease in housing affordability between 1980 and 2017 for most income levels. While extremely low-income households experienced an improvement in their housing affordability, this income group still bears the highest housing cost burden.

4.4.2. Location Affordability: A Cross-Sectional Overview

Except for Miami and Los Angeles, the metropolitan areas in this study are affordable to a household earning their respective area median income (Table IV-17). This outcome is largely a factor of housing being affordable, while transportation costs in many MSAs exceed the 15% of income threshold. Income and rent also vary widely between metropolitan areas with median gross rent being higher in higher-income MSAs (Figure IV-22; Table IV-17; Figure IV-23). Yet some MSAs, like San Diego, Los Angeles, and especially Miami, have rents that are much higher than their median income would suggest. Transportation costs, on the other hand, do not vary as much between MSAs and, as a result, do not show a clear relationship with income, perhaps due to the auto-dependent nature of urban form in the US. Interestingly, there is a strong positive relationship between housing and transportation costs (Figure IV-23). This relationship suggests that, rather than a tradeoff between the two cost-elements, MSAs that have a higher median gross rent, like San Jose, San Francisco, and Los Angeles, also tend to have higher average transportation costs.

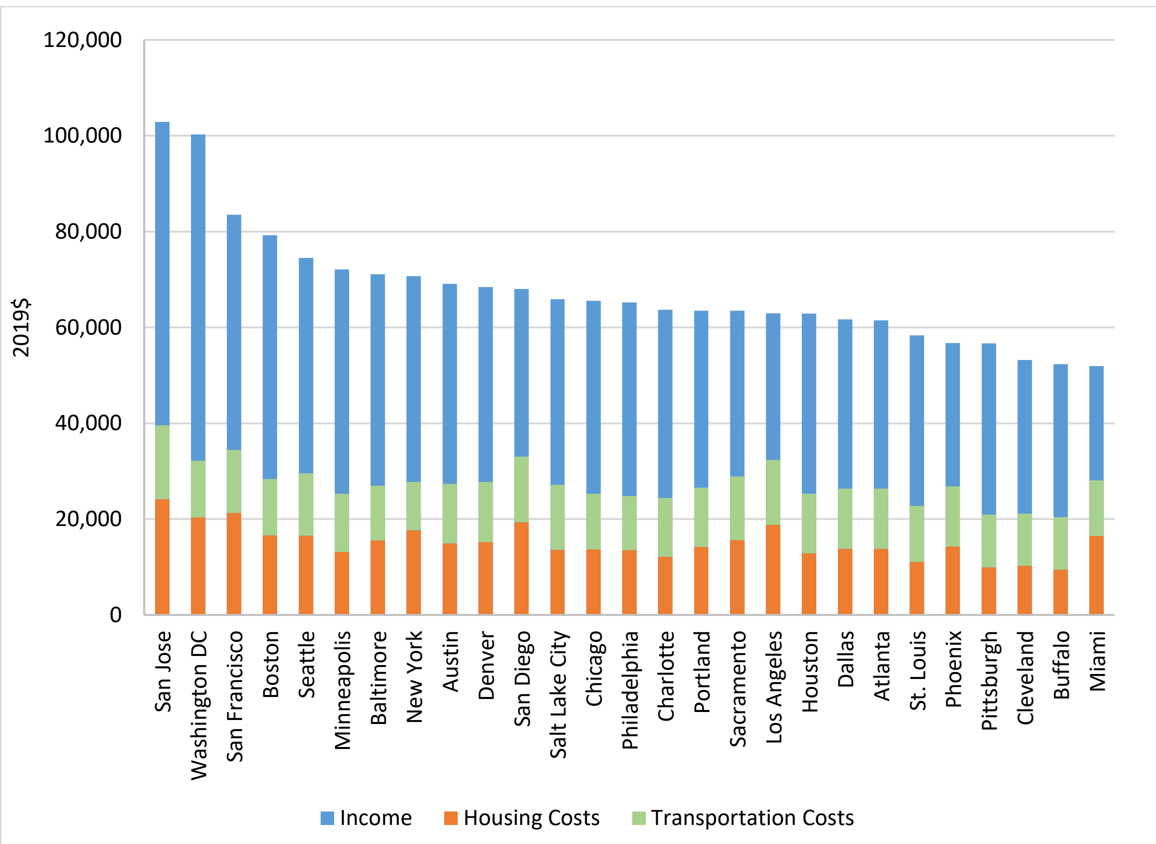

Figure IV-22: Income, Housing, and Transportation Costs by MSA
Note: MSAs in order of decreasing median income.

One explanation for the housing-transportation cost relationship is that the tradeoff between the two cost-elements might be mediated by transit level of service. Specifically, housing costs tend to be higher in MSAs with a higher average transit job accessibility, whereas transportation costs tend to be lower in transit-rich MSAs (Figure IV-23). Yet, the relationships between costs and accessibility might also be influenced by the presence of New York in the sample. While New York seems to weaken the positive association between accessibility and housing costs due to a relatively low median gross rent at the metropolitan level, it seems to be the main factor behind the negative relationship between accessibility and transportation costs. This suggests that, outside of New York, accessibility might have a weak effect on the tradeoff between housing and transportation costs, mainly due to a weak relationship with transportation costs.

Table IV-17: Housing and Transportation Costs and Affordability by MSA

MSA	Population (Millions)	Income (2019$)	Housing Costs (2019$)	Transport Costs (2019$)	Transit Job Accessibility	Housing Cost burden	Transport Cost burden	H+T Cost burden
Miami	5.8	51,918	16,490	11,593	85,200	31.1	21.8	52.1
Los Angeles	12.5	62,960	18,819	13,525	263,754	28.1	20.2	47.7
San Diego	3.1	68,044	19,344	13,695	85,054	24.9	17.6	42.2
New York	18.8	70,707	17,710	10,061	784,528	26.1	14.8	39.2
Phoenix	3.8	56,727	14,276	12,579	N/A	20.9	18.5	39.0
Sacramento	1.8	63,460	15,578	13,339	70,789	20.5	17.5	37.7
Atlanta	4.7	61,465	13,838	12,500	53,049	19.0	17.2	35.7
San Jose	1.7	102,888	24,142	15,430	N/A	21.3	13.6	34.8
Salt Lake City	1.1	65,881	13,630	13,502	131,738	17.7	17.6	34.7
Dallas	5.4	61,720	13,780	12,560	89,801	18.4	16.8	34.6
Charlotte	1.3	63,722	12,124	12,325	N/A	17.0	17.2	33.8
Houston	5.3	62,920	12,858	12,445	144,242	17.4	16.9	33.8
Portland	1.9	63,507	14,194	12,389	124,153	18.1	15.8	33.5
Austin	1.5	69,106	14,922	12,416	118,091	18.3	15.2	32.9
Denver	2.5	68,418	15,243	12,505	150,732	17.9	14.7	32.0
San Francisco	3.4	83,533	21,271	13,166	238,494	19.6	12.1	31.2
Seattle	3.2	74,540	16,563	13,019	129,149	17.4	13.7	30.7
Chicago	8.7	65,561	13,688	11,589	216,371	16.9	14.3	30.4
St. Louis	2.2	58,359	11,050	11,737	88,206	14.8	15.7	29.9
Cleveland	1.8	53,204	10,267	10,901	105,060	14.6	15.5	29.4

Philadelphia	5.5	65,251	13,558	11,250	230,722	15.7	13.0	27.9
Pittsburgh	1.7	56,675	9,934	11,037	105,282	13.4	14.9	27.9
Baltimore	2.3	71,128	15,551	11,393	152,974	16.3	11.9	27.6
Buffalo	0.9	52,309	9,453	10,991	93,667	12.9	15.0	27.3
Washington DC	4.9	100,280	20,357	11,815	358,953	17.5	10.2	27.1
Minneapolis	2.7	72,117	13,158	12,135	N/A	14.3	13.2	26.8
Boston	4.3	79,286	16,620	11,739	260,467	15.9	11.2	26.4

Note: MSAs in order of decreasing H+T Cost burden.

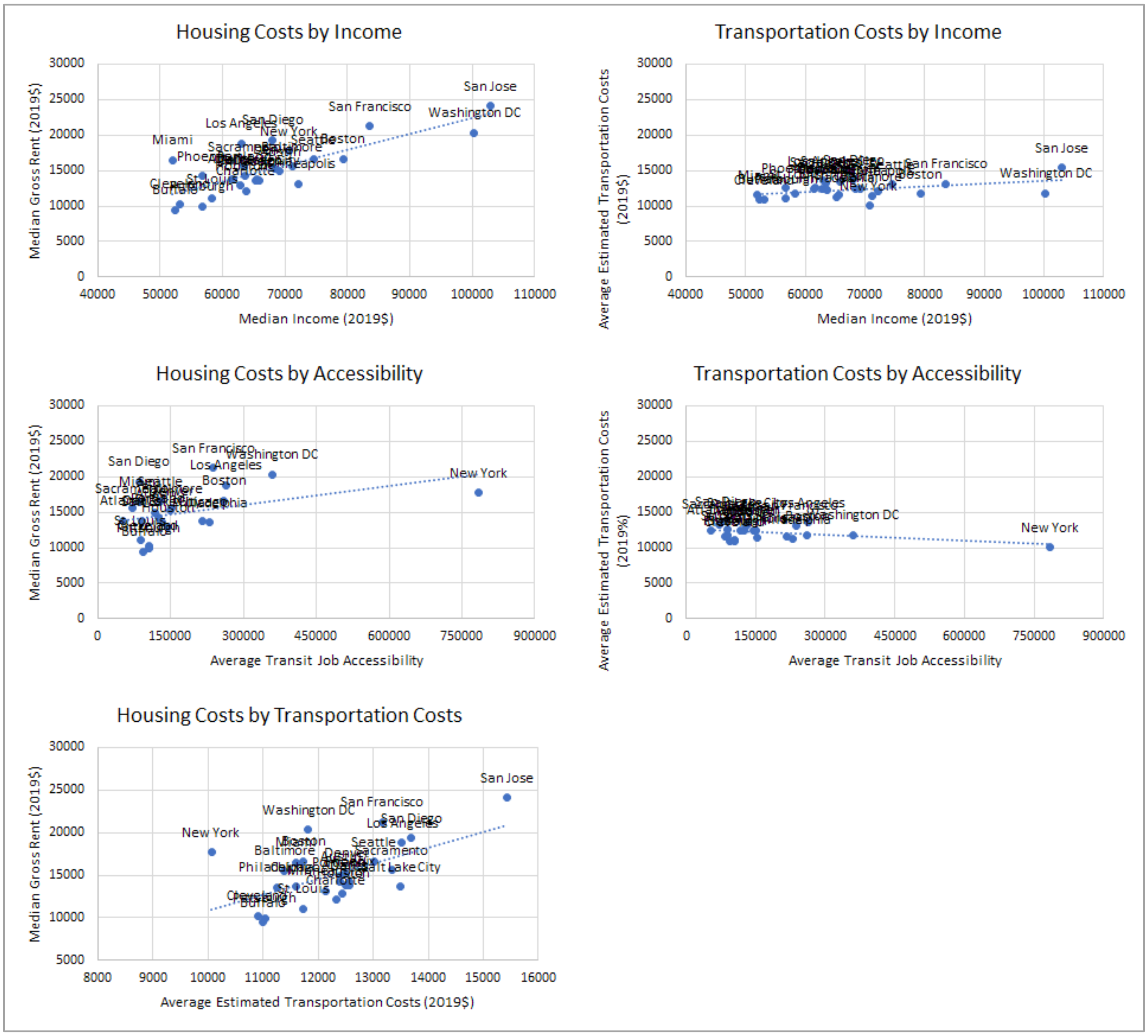

Figure IV-23: Housing and Transportation Costs by Income and Accessibility

As functions of cost and income, it could be expected that housing and transportation cost burdens will be positively associated with housing and transportation costs and negatively associated with income. Indeed, average housing and transportation cost burdens tend to increase with their respective costs at the metropolitan level (Figure IV-24). However, this relationship is stronger for housing than for transportation, in part due to the effect of MSAs like San Diego, New York, Los Angeles, and Miami, which have high median rents but middle-to-low median incomes (Figure IV-22). Transportation costs, on the other hand, increase with income at a slower rate than housing. As a result, transportation cost burden at the metropolitan level has only a weak positive relationship with transportation costs. These outcomes suggest that housing cost burden is strongly affected by housing costs. On the other hand, since transportation costs do not vary much between metropolitan areas, transportation cost burden is affected more by income.

Average metropolitan housing cost burden has a weak positive relationship with metropolitan median income while transportation cost burden has a strong negative relationship with income (Figure IV-24). The housing cost burden-income relationship suggests that, except in low-income - high rent MSAs like Miami and Los Angeles, households tend to consume more housing as their income increases. On the other hand, since transportation tends to be consumed at similar levels in different MSAs regardless of income, transportation tends to be more affordable in higher-income MSAs. Together, the effect of these outcomes is that the combined housing and transportation (H+T) cost burden at the metropolitan level tends to decrease as income increases, mainly due to a lower transportation cost burden in higher-income MSAs.

Accessibility seems to be a factor that mediates between income and combined housing and transportation cost burden at the metropolitan level (Figure IV-24). When New York is excluded, accessibility has a strong negative relationship with the combined cost burden of housing and transportation. This outcome is due to the negative relationship between accessibility and transportation cost burden alongside only a weak relationship between accessibility and housing cost burden when New York is excluded. One explanation for this relationship between accessibility and H+T cost burden is the strong positive relationship between accessibility and income ($r^2 = 0.56$; not shown). While MSAs with higher average transit accessibility also tend to have higher housing costs, these MSAs also tend to have a higher median income. As a result, the overall cost burden of housing and transportation tends to be lower in MSAs with higher transit accessibility.

The results imply that the majority of block groups have housing costs that are affordable to the household earning the area median income (Figure IV-25). Yet, in MSAs like New York, San Diego, Los Angeles, and especially Miami, the share of block groups that are affordable at the level of area median income is much lower than in the rest of the sample due to high housing costs and lower incomes.

The high shares of block groups that are affordable in high-income MSAs are misleading. MSAs like San Jose, San Francisco, and Seattle (Figure IV-25), which are at the higher end of the median income distribution, also tend to be at the high end of the housing and transportation cost distributions (Figure IV-25; Table IV-17). This implies that while housing and transportation might be affordable to the middle- and high-income households that live in these MSAs, costs are still unaffordable to lower-income households who are excluded from these MSAs due to high housing costs (Gyourko et al., 2013).

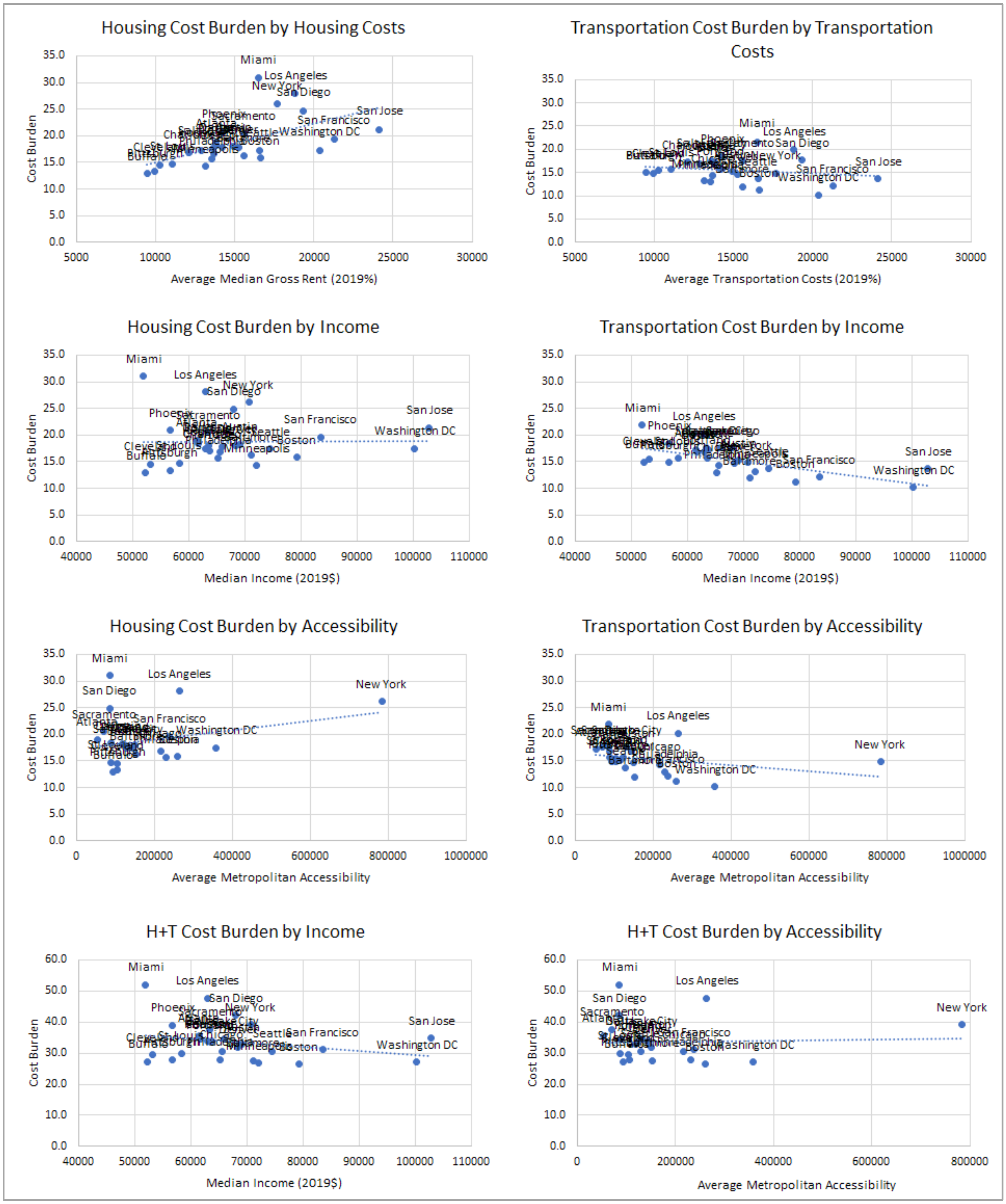

Figure IV-24: Average Housing, Transportation, and H+T Cost burdens by Costs, Income, and Accessibility

Note: Average Cost burden is based on Area Median Income.

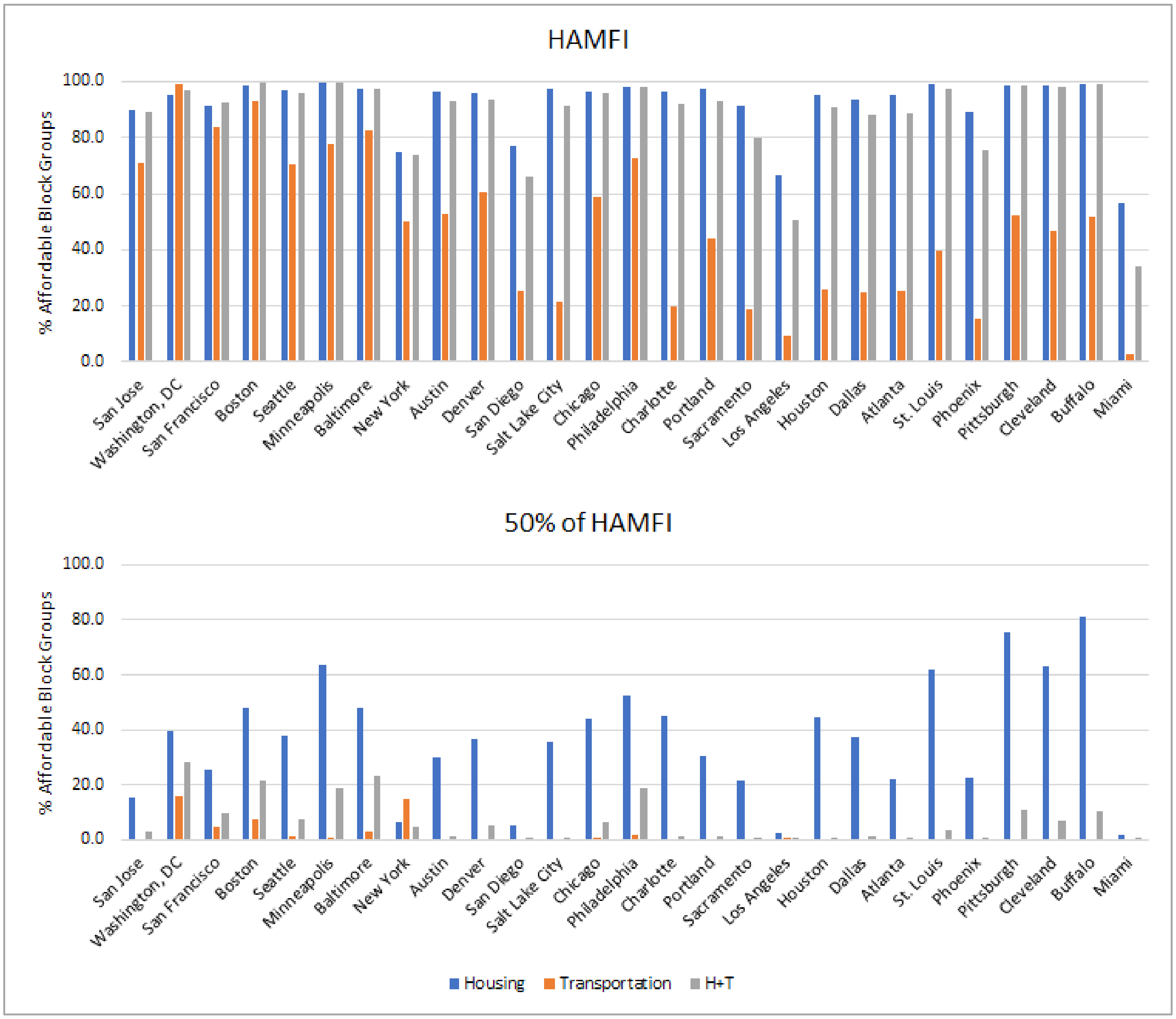

Figure IV-25: Share of Affordable Block Groups by MSA and Income Level
Note: MSAs in order of decreasing median income. HAMFI: HUD Area Median Family Income.

This interpretation also highlights a limitation of the neighborhood-level affordability measure. Since the measure is relative to area median income, it might fail to identify affordability problems for potential populations that are excluded from the region due to high housing costs. This limitation is partially overcome by the analysis of affordability for different income levels. In the high-cost regions, 80% and even 50% of area median income are often similar to the area median income in the middle- and lower-income MSAs. Hence, to consider whether a metropolitan area is affordable to the wider U.S. population, it might be more appropriate to compare affordability to the area median household in lower-income MSAs to affordability to the 50/80% of area median income household in the high-income MSAs. Such an analysis will show that higher-income MSAs that are associated with higher cost burdens than other middle- and low-income households.

In only six MSAs, more than fifty-percent of block groups have housing costs that are affordable to a household earning 50% of the area median income (Figure IV-25). These MSAs tend to be concentrated at the lower end of the income distribution (St. Louis, Pittsburgh, Cleveland, and Buffalo) or to have higher incomes relative to their position among the housing-cost distribution (Minneapolis and Philadelphia). In the majority of remaining MSAs, only a small share of block groups is affordable to households earning very low-incomes. And unaffordability is especially a problem in MSAs with a mismatch between their income level and level of housing costs (e.g., Los Angeles and Miami).

In terms of transportation costs, the share of block groups that are affordable tends to decrease with metropolitan median income (Figure IV-25). Among lower-income MSAs, Chicago, Philadelphia, Pittsburgh, and Buffalo stand out with a larger share of block groups having transportation costs that are affordable to the area median income household. Transportation might be affordable in these MSAs due to their rail systems or perhaps because of a good balance between the distribution of housing and employment in the region. However, due to the auto-dependent nature of U.S. urban form, only a low share of block groups in all the MSAs is affordable to very low-income households. MSAs that have an extensive rail system, like Washington DC, New York, and Boston, and San Francisco, have a larger share of block groups with transportation costs that are affordable to very low-income households. This supports the notion that accessibility can mediate between income and costs to provide more affordable locations.

The majority of block groups in most MSAs have combined housing and transportation costs that are affordable to the area median income household (Figure IV-25). Again, Miami and Los Angeles stand out as the MSAs with the lowest share of affordable block groups. In the rest of the MSAs in the sample, a large portion of their block groups are affordable, including in middle- and low-income MSAs which have lower shares of transportation-affordable block groups. These outcomes suggest that many block groups allow trading-off between housing and transportation costs. Yet, even among MSAs with relatively high shares of block groups with housing costs that are affordable to very low-income households, only a small share of block groups has combined housing and transportation costs that are affordable to very low-income households. The MSAs with a larger share of affordable block groups also tend to have a higher median income and a larger share of transportation-affordable block groups. This suggests that for low-income households, having the ability to reduce transportation costs is crucial to minimizing their overall location cost burden.

Table IV-18: Costs and Affordability by Neighborhood Type, Cross-Sectional Comparison

Station Type	Median Household Income ($2019)	Annual Median Gross Rent ($2019)	Annual Average Transport Costs ($2019)	Average Housing Cost burden	Average Transport Cost burden	Average H+T Cost burden
Average	78,589	15,963	11,925	21.0	15.7	35.9
Transit-Oriented Development	72,562	17,513	6,738	23.2	8.7	31.9
Non-Rail Pedestrian-Friendly	64,370	15,773	9,508	20.2	12.2	32.4
Rail-Oriented Intermediate	66,317	15,819	8,002	21.6	10.6	31.9
Non-Rail Intermediate	68,260	15,208	11,127	20.2	14.8	34.7
Transit-Adjacent Development	86,741	15,736	12,243	19.7	15.5	34.6
Auto-Oriented Development	86,493	16,311	13,438	21.3	17.6	38.3

Note: Average Block-Group Cost burden is based on Area Median Incomes.

Among the six neighborhood types, neighborhoods that are closer to rail stations (e.g., transit-oriented development and rail-oriented intermediate development) and the CBD (non-rail pedestrian-friendly development) tend to have the lowest average housing, transportation, and combined H+T cost burdens (Table IV-18). In these neighborhoods, the high levels of accessibility that rail and proximity to the CBD provide allow reducing transportation costs. Hence, although these neighborhoods tend to have lower incomes and to be less affordable in terms of housing costs, their overall affordability is still better than their non-rail counterparts or more suburban neighborhood types. Still, even the least affordable non-rail and auto-dependent neighborhood types have combined housing and transportation costs that are affordable to the area median income household.

4.4.3. Location Affordability: Neighborhood Housing and Transportation Affordability by Neighborhood Type

The descriptive and longitudinal analyses of affordability presented in the previous two sub-sections show that housing and transportation cost are relatively affordable to middle- and moderate-income households. For lower-income households, on the other hand, neighborhoods tend to be much less affordable, mainly due to the effect of transportation on the overall cost burden. The longitudinal analysis adds that the rate of change in housing costs and affordability over time varies between neighborhood types, in part due to low supplies of housing and a faster increase in rents relative to income in higher-density and rail-proximate neighborhoods.

This section builds on the previous two sections and provides, in three separate sub-sections, a more nuanced analysis of housing, transportation, and location affordability at the block-group level (Hypothesis 4). Specifically, the analyses in these sections examine how the various aspects of affordability vary by neighborhood type, transportation characteristics, and the diversity of neighborhoods at the metropolitan level. The results suggest that transit accessibility benefits in terms of transportation-cost savings might be larger than their positive relationships with housing costs. Consequently, transportation services contribute to making a location more affordable. Nonetheless, lower-income households in transit-rich neighborhoods are still cost burdened, which suggests that transportation improvements alone will not be able to solve the location affordability crisis.

4.4.3.1. Housing Cost burden

For most income groups, housing cost burden is higher in rail-proximate and pedestrian-friendly neighborhoods (Figure IV-26). On the other hand, transportation cost burden tends to be lower in these neighborhoods, and especially in those served by rail. As a result, combined housing and transportation cost burden is slightly lower in rail-proximate neighborhoods. Still, the share of income spent on housing, transportation, and their combined costs is higher in neighborhoods with lower median incomes relative to the area median income.

Housing cost burden varies by income group more than by neighborhood type (Figure IV-26). Lower-income neighborhoods exhibit higher cost burdens than in higher-income neighborhoods. For neighborhoods with extremely low income (less than 30% of area median income), housing costs in all neighborhood types account for more than fifty percent of their income level. This suggests that even if the average household in these neighborhoods eliminated its transportation costs altogether, for example, the neighborhood would still be considered unaffordable. Interestingly, among extremely low-income neighborhoods, TOD and rail-oriented intermediate neighborhoods are more affordable than their non-rail counterparts. In all other income groups, the reverse is the case, with rail-proximate neighborhoods being less affordable than their non-rail counterparts.

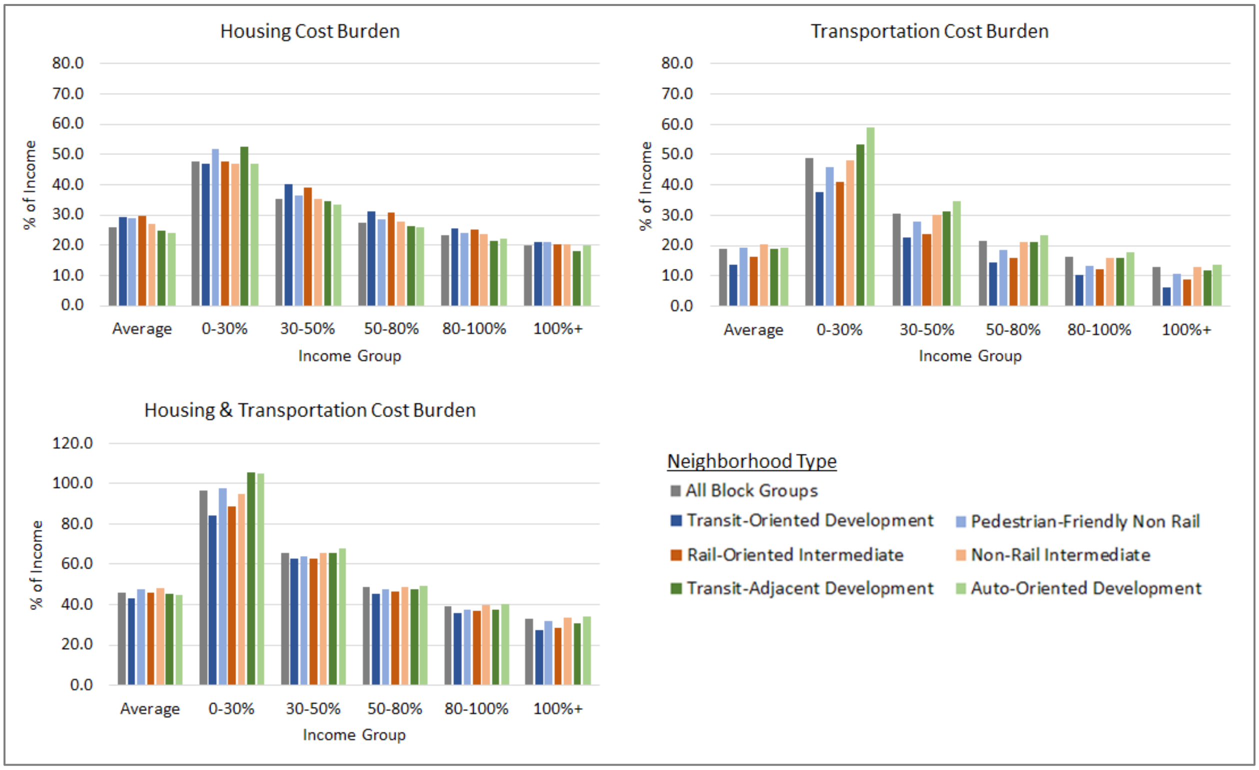

Figure IV-26: Average Cost burden by Income Group and Neighborhood Type

Note: Cost burden for the income group earning less than 30% of area median income is calculated relative to 20% of area median income; cost burden for the income group earning between 30-50% of area median income is calculated relative to 30% of area median income; cost burden for the income group earning between 50-80% of area median income is calculated relative to 50% of area median income; cost burden for the income group earning between 80-100% of area median income is calculated relative to 80% of area median income; cost burden for the income group earning 100%+ of area median income is calculated relative to area median income.

Cost burden in very low-income neighborhoods is slightly lower than in extremely low-income neighborhoods, yet all neighborhood types in this income group tend to exhibit a housing cost burden (Figure IV-26). On the other hand, housing cost burden is lower in moderate-income neighborhoods. While housing in neighborhoods with incomes at area median income or higher is considered affordable, they are less affordable to their income group than housing in moderate-income neighborhoods. This is a somewhat counter-intuitive finding, which might reflect the willingness of higher-income households to spend a larger share of their income on housing to consume more housing or to gain access to non-housing benefits like better access to transit, schools, or other amenities.

Mapping the housing cost burden in Atlanta, Boston, Los Angeles, and Portland shows that the distribution of housing affordability in a metropolitan area does not necessarily have a clear relationship with urban form and their historical urban development (Figure IV-27). In Atlanta and Portland, the majority of block groups throughout each metropolitan area are affordable to households earning 80% or more of their area median income. In Los Angeles, on the other hand, which also tends to be more auto-oriented, large sections of the inner urban ring are affordable to households earning 80% or more of area median income. At the same time, areas within downtown as well as in more suburban locations are much less affordable. Similarly, in Boston, affordable neighborhoods tend to be concentrated in more central locations but they also extend along rail lines to the north and to the south. Outside of the inner ring, however, neighborhoods tend to be unaffordable to the area median income household. These maps show that even in high cost-burdened MSAs like Los Angeles, Boston, and Portland, large sections of the region, including near rail stations, have housing costs that are affordable at least to households earning 80% of area median income.

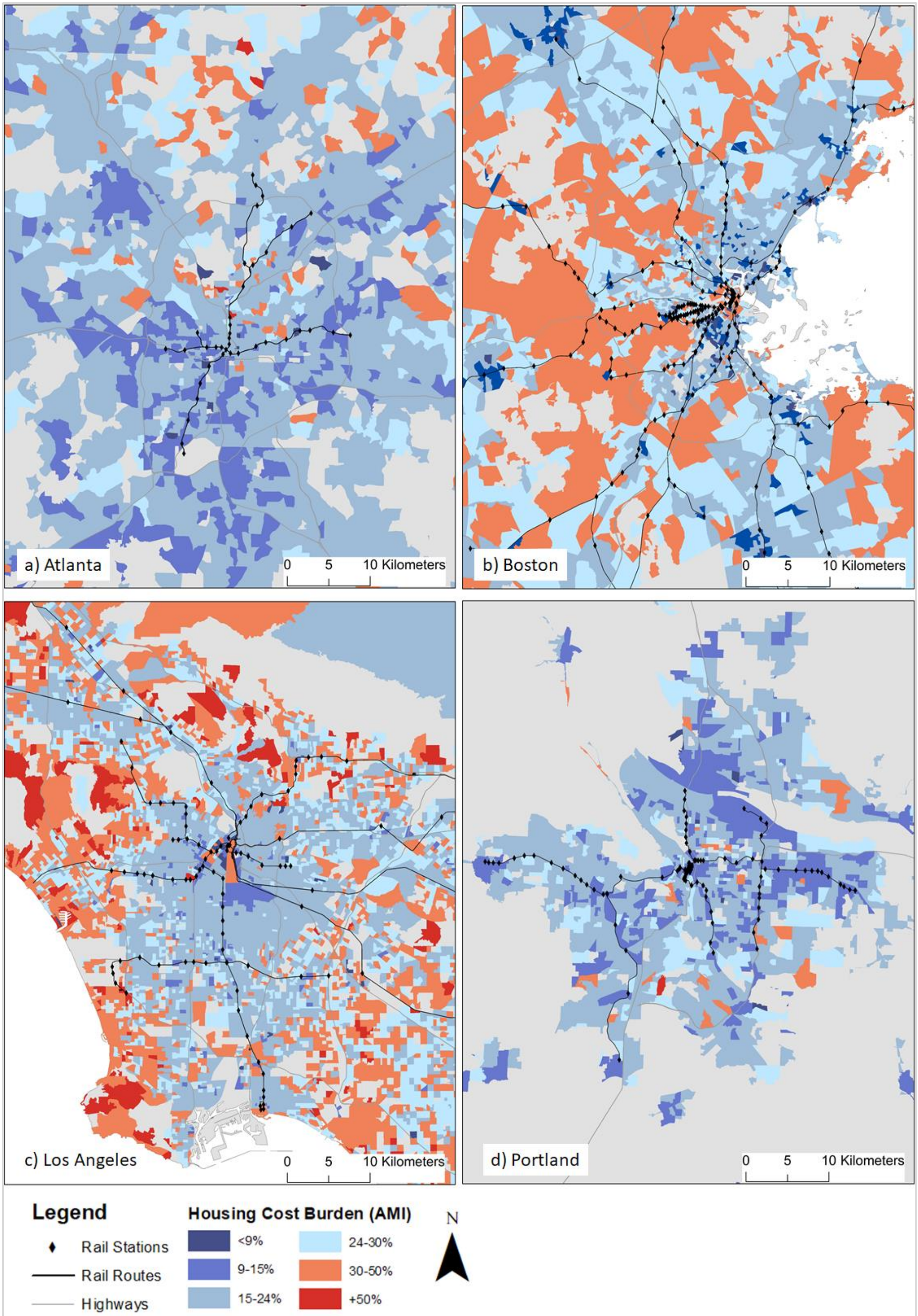

Figure IV-27: Housing Cost burden by Neighborhoods in Atlanta, Boston, Los Angeles, and Portland (2015)

Note: Cost burden levels are based on area median income (AMI). Neighborhoods with a cost burden below 9% of AMI are affordable to households earning 30% or more of AMI; neighborhoods with a cost burden between 9-15% of AMI are affordable to households earning 50% or more of AMI; neighborhoods with a cost burden between 15-24% of AMI are affordable to households earning 80% or more of AMI; neighborhoods with a cost burden between 24-30% of AMI are affordable to households earning 100% or more of AMI.

The results to this point suggest that housing affordability may be a function of neighborhood built-environment and transportation characteristics. To further examine the associations between these factors and housing affordability, a set of multilevel regression models are constructed on the average share of income spent on housing relative to area median income, whether a neighborhood is affordable to the household at 80% of area median income, and the share of 1- and 2-bedroom housing units in a neighborhood that rent for less than HUD's fair market rent (Table IV-19). The results are consistent across the models and are in line with the results on housing costs. Overall, block groups with higher shares of individuals age 25 to 39, new housing development, and median household income are associated with a higher housing cost burden, higher odds that a block group is unaffordable to households with income at 80% of area median income, and smaller shares of affordable 1- and 2-bedroom housing units. On the other hand, block groups with higher shares of small housing units are associated with housing being more affordable. In addition, after accounting for accessibility benefits, distance from the CBD is associated with a higher housing cost burden, suggesting that central locations are more affordable. However, the effect size of distance from the CBD is small and does not translate to affordability for moderate-income households.

In addition to neighborhood socio-demographic and housing characteristics, housing also tends to be less affordable in transit-rich neighborhoods. Most notable, higher transit job accessibility is associated with a higher housing cost burden and lower shares of affordable small housing units. As a result, neighborhoods with higher transit job accessibility are associated with higher odds of being unaffordable to moderate-income households. In a similar vein, distance from a rail station is associated with lower housing cost burdens and higher shares of affordable small housing units. However, the association between distance from a rail station and the odds of a neighborhood being unaffordable to moderate-income households is only marginally significant.

Accounting for transit accessibility reduces the relationship between neighborhood types and housing cost burden, which suggests that some of this relationship is due to accessibility benefits (Table IV-19). This effect is most notable in rail-oriented intermediate development and transit-oriented development, the two most transit-rich neighborhood types. After accounting for transit accessibility, rail-oriented intermediate development is negatively associated with housing cost burden, which suggests that unaffordability in these neighborhoods is often linked to higher transit accessibility benefits.

TODs, on the other hand, still have a positive association with housing cost burden even after accounting for transit accessibility. In addition, TOD block groups are also associated with a higher probability of being unaffordable to households earning 80% of area median income, in part due to lower shares of 1- and 2-bedroom housing units in TODs relative to auto-oriented development. Together with the results from the housing costs section, these results suggest that part of the unaffordability of TODs is not due to their transportation benefits but rather other factors, including for example, their scarcity regionwide or their pedestrian-friendly environment.

Housing tends to be more affordable in lower density rail and non-rail neighborhoods with lower levels of pedestrian-friendly built environments. Relative to auto-oriented development, rail and non-rail intermediate development and transit-adjacent neighborhoods are associated with lower housing cost burdens. Transit-adjacent neighborhoods are also associated with a higher share of small housing units that are affordable, resulting in lower odds of neighborhoods of this type being unaffordable at 80% of area median income.

Table IV-19: Housing Affordability Models

VARIABLES	Housing Cost burden Coef. (Std Err)	Housing Cost burden* Accessibility Coef. (Std Err)	% Affordable 1-2 Bedroom Housing Units Coef. (Std Err)	Neighborhood Affordable at 80% Area Median Income Coef. (Std Err)
Block-group Level				
% Black	-0.019***	-0.019***	0.049***	-0.017***
	(0.001)	(0.001)	(0.005)	(0.0008)
% Hispanic	-0.037***	-0.038***	0.105***	-0.016***
	(0.002)	(0.002)	(0.006)	(0.0008)
% Age 25-39	0.057***	0.051***	-0.366***	0.019***
	(0.003)	(0.003)	(0.011)	(0.002)
Average Household Size	0.004	0.004	3.290***	0.083***
	(0.052)	(0.052)	(0.195)	(0.028)
% Small Housing Units	-0.054***	-0.057***	0.608***	-0.022***
	(0.001)	(0.002)	(0.005)	(0.0009)
% New Development	0.035***	0.035***	-0.157***	0.014***
	(0.002)	(0.002)	(0.006)	(0.0009)
Median Household Income (1000s)	0.1219***	0.121***	-0.130***	0.035456***
	(0.001)	(0.001)	(0.003)	(0.0007)
Neighborhood Type (Reference: Auto-oriented)				
Transit-adjacent	-0.688***	-0.768***	2.012***	-0.246***
	(0.149)	(0.149)	(0.547)	(0.090)
Non-rail intermediate	-0.155**	-0.163**	0.035	-0.064*
	(0.065)	(0.065)	(0.242)	(0.038)
Rail-oriented intermediate	0.5642***	-0.223**	-1.704***	0.062
	(0.104)	(0.111)	(0.427)	(0.063)
Non-rail pedestrian-friendly	0.073	0.013	-4.242***	0.019
	(0.104)	(0.104)	(0.406)	(0.059)
Transit-oriented	1.643***	0.700***	-7.138***	0.274***
	(0.136)	(0.144)	(0.56634)	(0.078)
Distance to Highway Ramp (Km)	-0.039***	-0.044***	0.339***	-0.014*
	(0.015)	(0.015)	(0.053)	(0.008)
Distance to Rail (Km)	-0.007**	-0.017***	0.073***	0.004*
	(0.003)	(0.003)	(0.013)	(0.002)
Distance to CBD (Km)	-0.008***	0.007***	-0.006	-0.00003
	(0.002)	(0.002)	(0.007)	(0.001)
Job Accessibility		0.001***	-0.007***	0.0003***
		(0.00007)	(0.0003)	(0.00003)
Metropolitan Level				
Population (1000s)	0.0007***	0.001***	-0.0003	0.0003***
	(0.0002)	(0.0002)	(0.0004)	(0.00008)
Median House Value (1000s)	-0.0006	-0.001	0.036***	0.0007
	(0.007)	(0.007)	(0.011)	(0.003)

Constant	10.221***	10.454***	8.629**	-5.334***
	(2.036)	(2.035)	(3.396)	(0.698)
Observations	52,818	52,573	61,930	52,573
Number of groups	23	23	23	23
Wald test	49653***	50311***	42335***	8935***
Linear Regression test	22247***	22284***	4507***	9933***

*** p<0.01, ** p<0.05, * p<0.1

The analysis of housing costs showed that the supply of housing in neighborhoods that serve as alternatives to TODs can moderate the higher housing costs in TODs. Applying the same analysis to housing affordability reveals similar outcomes (Table IV-20). The interaction between the share of non-rail pedestrian-friendly housing units in a metropolitan area and neighborhood types has a negative association with housing cost burden at all neighborhood types and with the odds of a block group being affordable to 80% of area median income. This suggests that the share of non-rail pedestrian-friendly housing units has a moderating effect on housing cost burden relative to its effect on affordability in auto-oriented development, which leads to neighborhoods being more affordable to lower-income households.

A larger share of rail-oriented intermediate development housing units also has a moderating effect on housing cost burden, though the process through which this occurs is different from the share of housing units in non-rail pedestrian-friendly housing development. Specifically, the share of rail-oriented intermediate housing units has a negative association with housing cost burden and the odds of a neighborhood being unaffordable at 80% of area median income. At the same time, the interactions between the share of rail-oriented intermediate housing units and the neighborhood types have a positive association with housing affordability. This suggests that while he share of rail-oriented intermediate housing units in a metropolitan area is associated with greater affordability, this effect is smaller in neighborhood types that are not auto-oriented development.

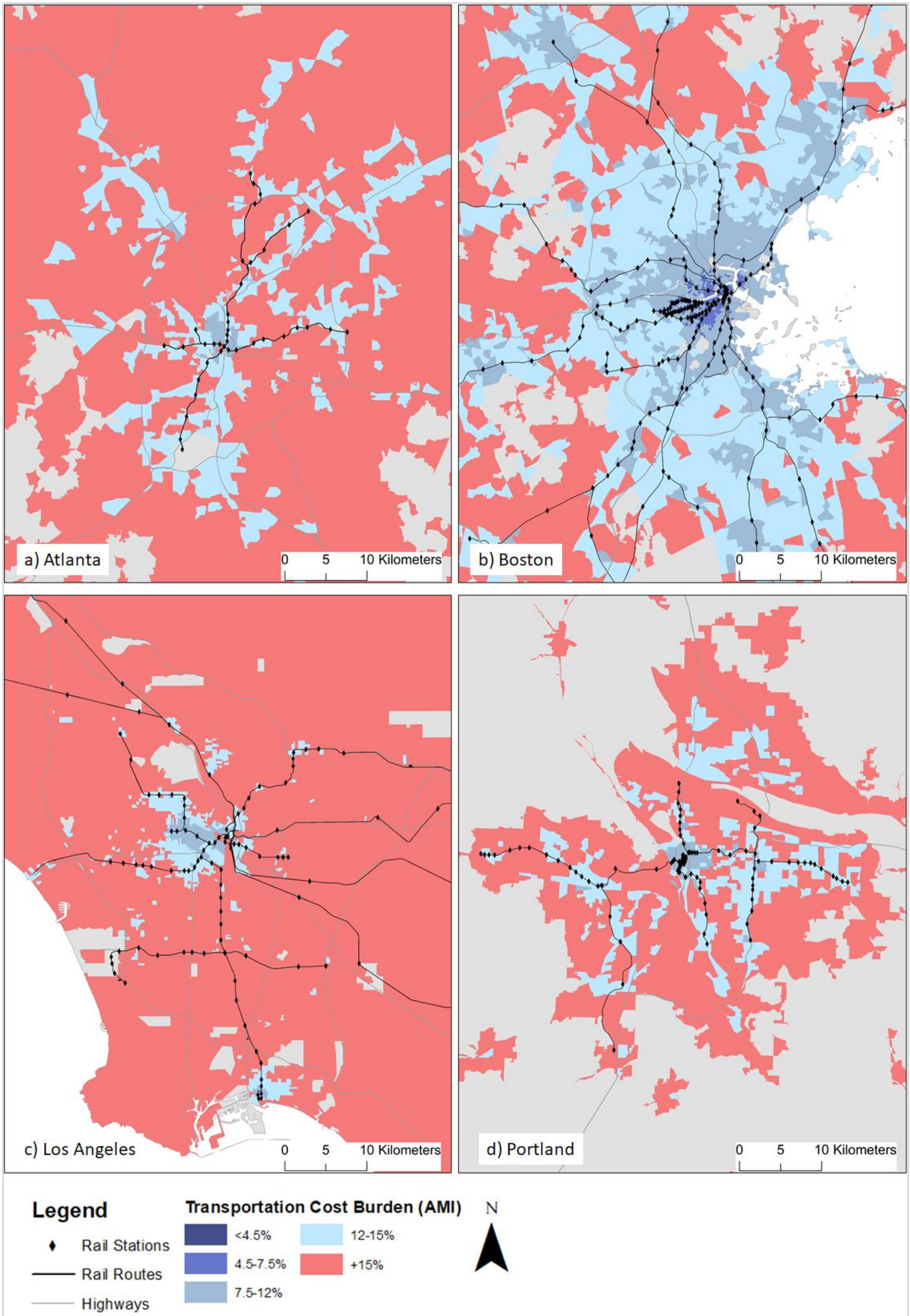

Figure IV-28: Transportation Cost burden by Neighborhoods in Atlanta, Boston, Los Angeles, and Portland

Note: Cost burden levels are based on area median income. Neighborhoods with a cost burden below 4.5% of AMI are affordable to households earning 30% or more of AMI; neighborhoods with a cost burden between 4.5-7.5% of AMI are affordable to households earning 50% or more of AMI; neighborhoods with a cost burden between 7.5-12% of AMI are affordable to households earning 80% or more of AMI; neighborhoods with a cost burden between 12-15% of AMI are affordable to households earning AMI or higher.

Table IV-20: Housing Supply on Housing Affordability Models

	Housing Cost burden		Neighborhood Affordable at 80% Area Median Income	
	Pedestrian-Friendly Housing Unit Share	Rail Intermediate Housing Unit Share	Pedestrian-Friendly Housing Unit Share	Rail Intermediate Housing Unit Share
VARIABLES	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)
Transportation Characteristics				
Distance to Highway Ramp (Km)	-0.042***	-0.046***	-0.029***	-0.016*
	(0.015)	(0.015)	(0.009)	(0.008)
Distance to Rail (Km)	-0.015***	-0.018***	-0.009***	0.00267
	(0.003)	(0.003)	(0.002)	(0.002)
Distance to CBD (Km)	0.006***	0.006***	0.012***	0.0004
	(0.002)	(0.002)	(0.001)	(0.001)
Job Accessibility	0.001***	0.001***	-0.0004***	0.0003***
	(0.00007)	(0.00007)	(0.00004)	(0.00004)
Neighborhood Type (Reference: Auto-oriented)				
Transit-adjacent	0.280	-1.178***	-0.115	-0.474***
	(0.290)	(0.228)	(0.177)	(0.138)
Non-rail intermediate	0.268**	-0.127	-0.464***	-0.153***
	(0.118)	(0.083)	(0.080)	(0.049)
Rail-oriented intermediate	0.527**	-0.605***	-0.428**	-0.541***
	(0.230)	(0.184)	(0.170)	(0.125)
Non-rail pedestrian-friendly	0.751***	-0.270*	-0.368**	-0.138*
	(0.208)	(0.139)	(0.146)	(0.080)
Transit-oriented	1.188***	-0.129	0.117	0.290*
	(0.306)	(0.252)	(0.220)	(0.152)
% Housing Units (Reference: Auto-oriented)	0.008	-0.521**	-0.081	-0.168**
	(0.183)	(0.207)	(0.104)	(0.072)
Transit-adjacent	-0.141***	0.049**	-0.019	0.026**
	(0.034)	(0.020)	(0.020)	(0.010)
Non-rail intermediate	-0.053***	-0.001	0.008	0.014***
	(0.012)	(0.008)	(0.008)	(0.004)
Rail-oriented intermediate	-0.097***	0.037***	-0.048**	0.042***
	(0.027)	(0.013)	(0.021)	(0.007)
Non-rail pedestrian-friendly	-0.079***	0.038***	-0.028**	0.021***
	(0.018)	(0.012)	(0.013)	(0.006)
Transit-oriented	-0.059*	0.066***	-0.080***	0.011
	(0.032)	(0.015)	(0.026)	(0.008)
Constant	10.152***	10.765***	-3.860***	-5.210***
	(1.627)	(1.811)	(0.9312)	(0.637)
Observations	52,573	52,573	52,573	52,573
Number of groups	23	23	23	23
Wald test	50406***	50393***	9871***	8942***
Linear Regression test	22022***	16182***	18396***	7564***

*** p<0.01, ** p<0.05, * p<0.1
Note: Full models in Table VII-5.

4.4.3.2. Transportation Cost burden

Similar to the trends in housing cost burden across neighborhood types and income groups, transportation cost burden is highest for lower-income groups (Figure IV-26). Among all income groups, transportation cost burden is lower in transit-oriented development and rail-oriented intermediate development and highest in auto-oriented development. For the higher-income groups, the lower transportation costs in transit-rich neighborhoods mean that transportation is considered affordable. On the other hand, the lowest two income levels are still cost burdened by transportation even in transit-rich neighborhoods. These outcomes suggest that even if lower-income households are able to reduce their transportation costs by living near transit, they are not able to reduce costs by enough for them to be considered affordable. One explanation for these results is that, while transit-rich neighborhoods allow accessing more employment opportunities, most households might still need to own a private vehicle in order to access their specific place of work, maintain their employment status, and access non-work destinations which might be harder to reach using transit.

Mapping transportation cost burden in Atlanta, Boston, Los Angeles, and Portland shows that transportation tends to be more affordable around each of the metropolitan area's CBD as well as along rail routes (Figure IV-28). This trend is the clearest in Atlanta and Portland, in which the CBD is affordable at 80% of area median income while neighborhoods along rail lines are affordable at the level of area median income. However, farther from the CBD and rail stations, neighborhoods tend to be unaffordable even at the level of area median income. This spatial distribution of transportation cost burdens is even more pronounced in Los Angeles, in which neighborhoods have affordable transportation costs only in and near downtown. Moreover, while

Atlanta, Los Angeles, and Portland have neighborhoods that are affordable at 80% of area median income or higher, only a very small number of neighborhoods have transportation costs that are affordable at lower-income levels.

The development of Boston around its rail system over the years produces a different geography of transportation cost burdens than in the other three MSAs. In Boston, the extension of rail service farther out from the CBD, and the development of the metropolitan area around rail service, allows households to reduce their transportation costs by using transit. As a result, a wide ring of central-city and inner-suburban neighborhoods are affordable to households at the area median income, while closer to the CBD neighborhoods are affordable at 80% of area median income. Still, only a small share of neighborhoods in the MSA are affordable to households earning 50% of area median income or lower.

To further examine the factors that affect transportation affordability, several multilevel models were constructed to examine the association between neighborhood built-environment and transportation characteristics and two measures of transportation affordability: transportation cost burden and whether transportation costs are affordable at 80% of area median income (Table IV-21). The models follow the results from the transportation costs section and show that the ability to substitute owning and using a private vehicle with transit use is also associated with better transportation affordability. Most notable, transit job accessibility is negatively associated with transportation cost burden as well as with the odds of a neighborhood being unaffordable to moderate-income households. According to the CBD Models, an increase of one-million jobs that are accessible by transit, representing the move from transit-adjacent to transit-oriented development, is associated with a 3% decrease in transportation cost burden and a 4.1 decrease in the odds of a neighborhood being unaffordable to moderate-income households.

Distance from the CBD and a rail station, two additional measures that are associated with better transit access, are also associated with lower transportation affordability. Specifically, all else being equal, neighborhoods that are farther from the CBD or a rail station are associated with a higher transportation cost burden and with higher odds of a neighborhood being unaffordable to moderate-income households. However, the effect sizes that are assigned to these factors are small after accounting for transit job accessibility. This suggests that much of the transportation-benefits that are associated with proximity to rail and the CBD stem from their accessibility benefits.

In addition, rail-proximate and more pedestrian-friendly built environments are associated with better transportation affordability, even after accounting for neighborhood transportation benefits. Among rail-proximate neighborhoods, transportation cost burdens are, on average, 1% lower in rail-oriented intermediate development and 1.4% lower in TODs compared to auto-oriented development. This suggests that rail-proximate neighborhoods have a transportation-cost saving element, perhaps walkability, that is not accounted for by transit accessibility. Combined with the accessibility benefits in these neighborhoods, the full transportation-cost discount in these rail neighborhoods might be as high as 4-5% compared to auto-oriented neighborhoods. Interestingly, non-rail neighborhoods with higher densities and more pedestrian-friendly environments also provide a considerable cost-burden discount compared to auto-oriented neighborhoods. This is perhaps thanks to these neighborhoods' walkability benefits over auto-oriented development or that bus service in these neighborhoods allows their residents to reduce car ownership and use.

Table IV-21: Transportation Affordability Models

	Transportation Cost Burden		Affordable to 80% AMI	
	CBD Model	Rail Model	CBD Model	Rail Model
Variables	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)
Neighborhood Type (Reference: Auto-Oriented Development)				
Transit-Adjacent	-0.234***	-0.262***	-0.255**	-0.60
	(0.038)	(0.039)	(0.115)	(0.115)
Non-Rail Intermediate	-0.826***	-1.019***	-1.257***	-1.39044***
	(0.017)	(0.017)	(0.057)	(0.056)
Rail-Oriented Intermediate	-1.031***	-1.155***	-1.651***	-1.517***
	(0.030)	(0.031)	(0.086)	(0.086)
Non-Rail Pedestrian-Friendly	-1.427***	-1.750***	-1.960***	-2.144***
	(0.028)	(0.028)	(0.083)	(0.082)
Transit-Oriented Development	-1.351***	-1.528***	-2.237***	-2.146***
	(0.040)	(0.041)	(0.125)	(0.124)
Transportation Characteristics				
Highway Ramp Distance (1000s)	0.039***	0.070***	0.119***	0.122***
	(0.004)	(0.004)	(0.020)	(0.019)
CBD Distance (1000s)	0.026***		0.062***	
	(0.0004)		(0.002)	
Rail Distance (1000s)		0.018***		0.073***
		(0.0008)		(0.005)
Job Accessibility (1000s)	-0.003***	-0.003***	-0.004***	-0.005***
	(0.00002)	(0.00002)	(0.0001)	(0.0001)
Constant	10.491***	10.535***	0.854	1.168
	(2.320)	(2.330)	(3.652)	(3.404)
Observations	63,905	63,905	63,905	63,905
Number of groups	23	23	23	23
Wald	342911***	322097***	6897***	7056***
LR test	71592***	69119***	19861***	18430***

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Notes: Full models in Table VII-6. Affordable to 80% AMI models: 0=Affordable; 1=Unaffordable.

4.4.3.3. Neighborhood Cost Burden

The bid-rent theory describes a tradeoff between housing and transportation costs, which suggests that factors that are associated with reducing transportation costs, such as transit accessibility, are associated with higher housing costs. The results in the previous sections support the tradeoff argument, both in terms of costs and affordability. Yet the effect of this tradeoff on location affordability—housing and transportation affordability—is difficult to calculate. Whether a factor like transit job accessibility or a TOD neighborhood, which are both associated with lower transportation costs but higher housing costs, produce a higher or lower combined housing cost burden depends on the effect of each of these variables on housing and transportation costs separately. Hence, it is important to evaluate the association between each of these factors and combined housing and transportation affordability.

Mapping location affordability in Atlanta, Boston, Los Angeles, and Portland suggests that many neighborhoods tend to be affordable thanks to more affordable housing costs and despite unaffordable transportation costs (Figure IV-29). This is mainly evident in Atlanta, Los Angeles, and Portland, where transportation cost burdens tend to be high outside of the CBD and rail-proximate neighborhoods while the neighborhoods with lower housing cost burdens are more common regionwide. At the same time, the neighborhoods that are affordable in these MSAs tend to be affordable to households at 80% of area median income or higher but not to lower-income households. In Los Angeles and Portland, affordable neighborhoods extend outward from the CBD along rail lines, mainly due to lower housing cost burdens. This suggests that farther from the CBD, even where transportation is not considered affordable, rail service enables keeping transportation costs low enough to not outweigh the lower housing costs in these neighborhoods.

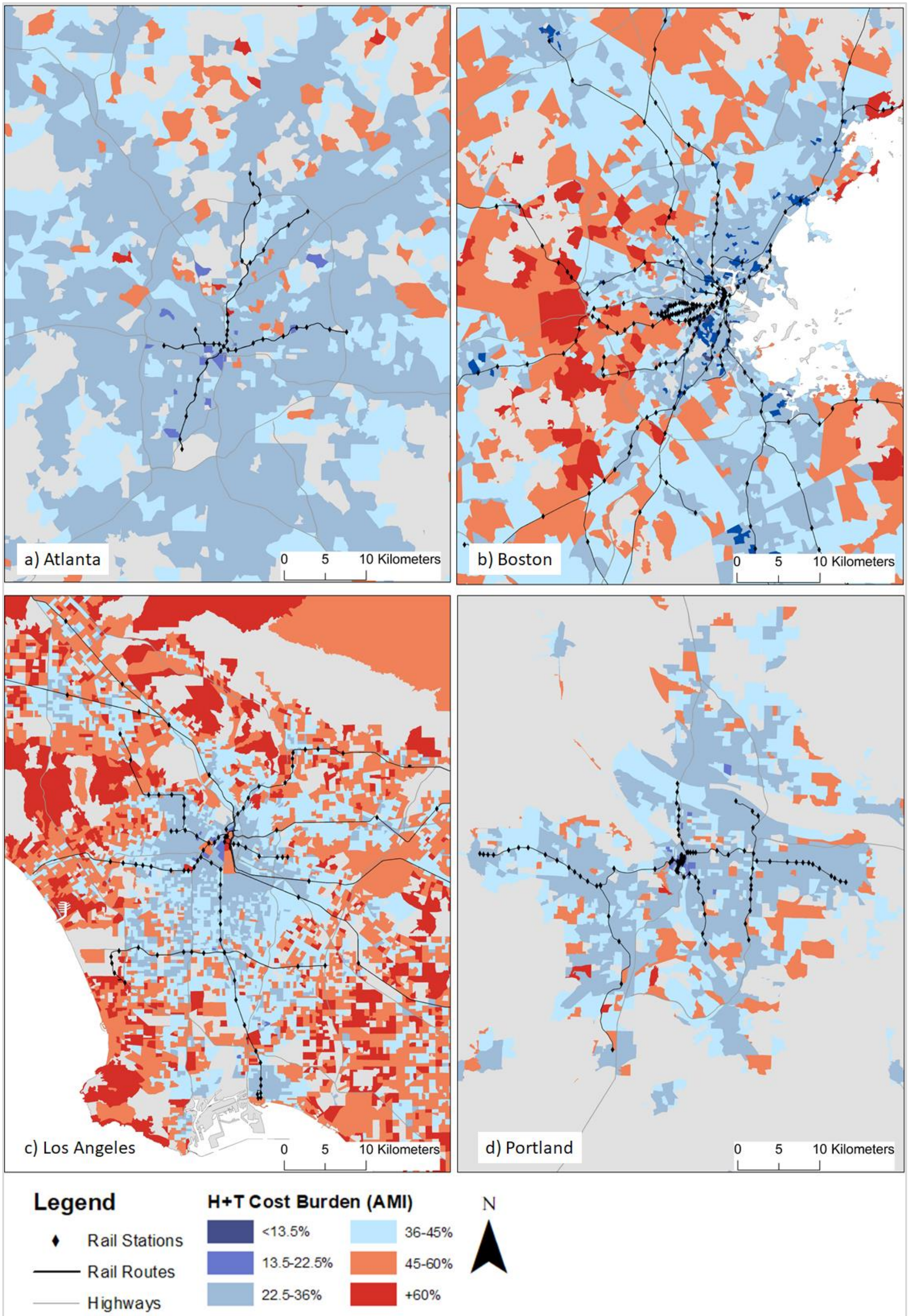

Figure IV-29: Neighborhood Cost Burden by Neighborhoods in Atlanta, Boston, Los Angeles, and Portland

Note: Cost-burden levels are based on area median income. Neighborhoods with a cost burden below 13.5% of AMI are affordable to households earning 30% or more of AMI; neighborhoods with a cost burden between 13.5-22.5% of AMI are affordable to households earning 50% or more of AMI; neighborhoods with a cost burden between 22.5-36% of AMI are affordable to households earning 80% or more of AMI; neighborhoods with a cost burden between 36-45% of AMI are affordable to households earning AMI or higher.

In Boston, on the other hand, neighborhoods that have unaffordable housing costs but affordable transportation costs are not affordable when the two costs are combined. This effect mainly occurs in the inner-suburban ring and along the eastern rail corridor. In these areas, transportation cost burden tends to be affordable at the area median income but housing tends to be unaffordable. As a result, the combined costs are unaffordable, even at area median income. Together, these maps suggest that location affordability is mainly influenced by housing cost burden. Where there is lower housing cost burden but a higher transportation cost burden, the location might still be affordable. On the other hand, where housing cost burden is high and transportation cost burden is low, the location is more likely to be unaffordable.

The lower variability in housing costs across neighborhood types relative to transportation costs, and the relative affordability of housing across neighborhood types relative to transportation, means that transportation improvements might have a stronger effect on transportation costs and affordability than on housing costs and affordability. Put differently, since the difference in transportation costs between auto-oriented development and transit-oriented development is larger than the difference between the two types of neighborhoods in terms of housing costs, a move from auto-oriented development to transit-oriented development will produce larger transportation-cost savings than housing-cost increases. As a result, transit-oriented development tends to be more affordable than auto-oriented development.

These observations are also supported by the results of a set of multilevel regression models on neighborhood cost burden and whether a neighborhood is affordable at 80% of area median income (Table IV-22). In particular, transit job accessibility is negatively associated with location cost burden and with the odds of a neighborhood being unaffordable to moderate-income households. According to the CBD Model, an increase of one-million jobs accessible by transit, which represents a move from auto-oriented to transit-oriented development, is associated with a 1.8% decrease in location cost burden. This relationship is also in line with the results of the previous models on housing and on transportation cost burdens. These models showed that a similar increase in accessibility is associated with a 1% increase in housing cost burden and a 3% decrease in transportation cost burden. These results suggest that the benefits from transit may outweigh the added costs to housing.

Accounting for transportation characteristics, and transit accessibility in particular, reduces the effect sizes that are associated with neighborhood types, and especially in rail-proximate neighborhoods. Yet the neighborhood types still have a significant negative association with the two neighborhood affordability measures even after accounting for transportation characteristics. These results suggest that less auto-oriented neighborhoods are associated with lower neighborhood cost burdens and therefore also lower odds of being unaffordable to moderate-income households. One explanation for these results is that the neighborhood type variables capture factors that are not accounted for by transportation characteristics, for example walkability benefits or lower housing costs. Interestingly, the greatest effect sizes are associated with rail-oriented intermediate and non-rail pedestrian-friendly neighborhoods. TODs, on the other hand, have the smallest effect on neighborhood cost burden after accessibility is accounted for. Together with the high levels of accessibility in rail-oriented intermediate and non-rail pedestrian-friendly neighborhoods, these results suggest that these neighborhoods might serve as affordable alternatives to housing in TOD, especially for lower-income households.

Table IV-22: Location Affordability Models

Variables	Location Cost Burden: Neighborhood Type Coef. (Std Err)	Location Cost Burden: Rail Model Coef. (Std Err)	Location Cost Burden: CBD Model Coef. (Std Err)	Neighborhood Affordable at 80% Area Median Income: Rail Model Coef. (Std Err)	Neighborhood Affordable at 80% Area Median Income: CBD Model Coef. (Std Err)
Transportation Characteristics					
Distance to Highway Ramp (Km)	0.040***	-0.031**	0.018	-0.035***	-0.017*
	(0.015)	(0.015)	(0.015)	(0.009)	(0.009)
Distance to Rail (Km)		0.028***		0.009***	
		(0.002)		(0.001)	
Distance to CBD (Km)			0.005		0.001
			(0.003)		(0.002)
Job Accessibility		-0.002***	-0.002***	-0.0004***	-0.0005***
		(0.00007)	(0.00006)	(0.00004)	(0.00004)
Neighborhood Type (Reference: Auto-oriented)					
Transit-adjacent	-0.990***	-0.636***	-0.761***	-0.216**	-0.261***
	(0.156)	(0.155)	(0.156)	(0.095)	(0.095)
Non-rail intermediate	-1.151***	-0.685***	-0.937***	-0.393***	-0.480***
	(0.066)	(0.068)	(0.067)	(0.045)	(0.044)
Rail-oriented intermediate	-2.856***	-1.001***	-1.208***	-0.782***	-0.854***
	(0.105)	(0.116)	(0.116)	(0.072)	(0.071)
Non-rail pedestrian-friendly	-1.837***	-0.977***	-1.381***	-0.664***	-0.798***
	(0.106)	(0.109)	(0.107)	(0.068)	(0.066)
Transit-oriented	-2.735***	-0.441***	-0.709***	-0.511***	-0.600***
	(0.139)	(0.150)	(0.150)	(0.089)	(0.089)
Constant	30.805***	29.301***	30.026***	-3.136**	-2.901**
	(3.580)	(3.511)	(3.569)	(1.321)	(1.329)
Observations	52,818	52,573	52,573	52,573	52,573
Number of groups	23	23	23	23	23
Wald test	90857***	94375***	93628***	9856***	9871***
Linear Regression test	49894***	48061***	50516***	23426***	24545***

*** p<0.01, ** p<0.05, * p<0.1

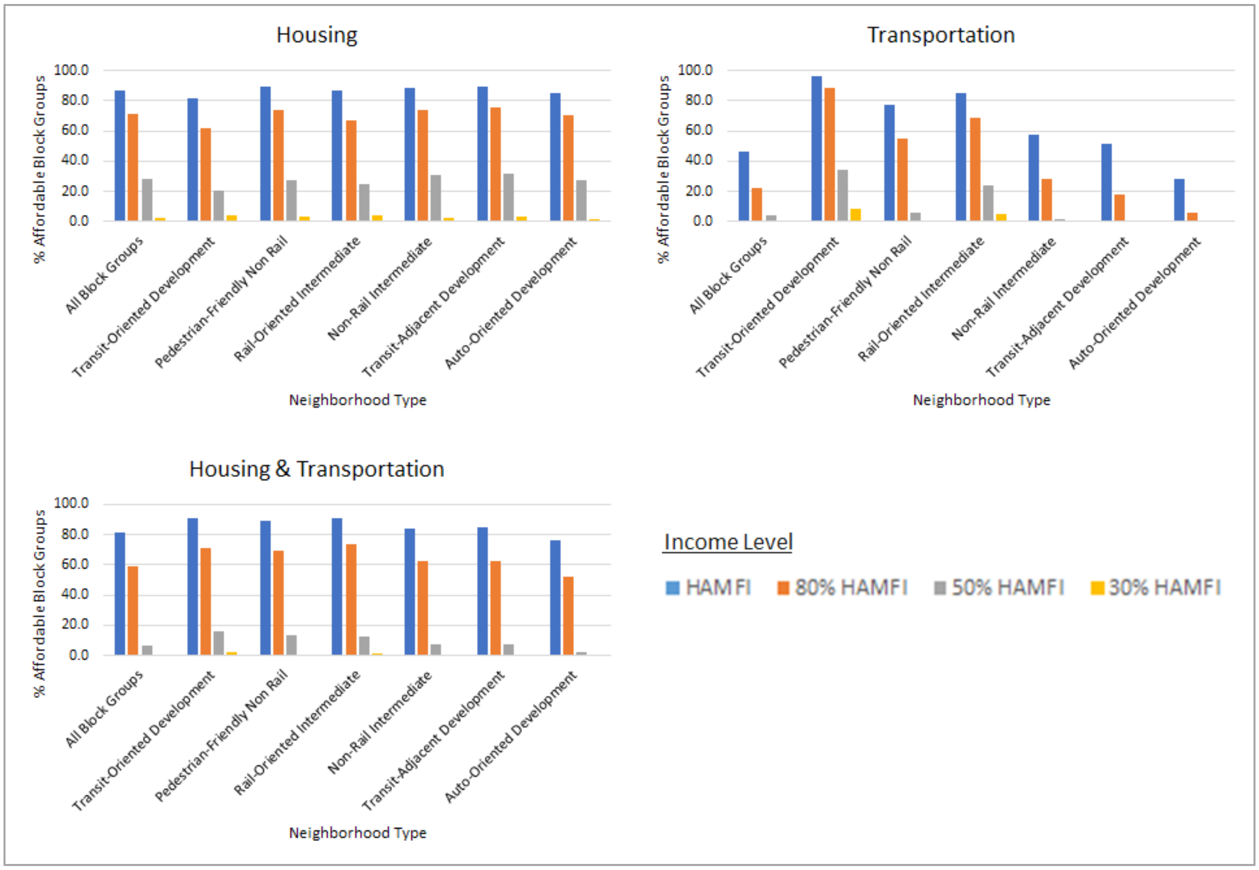

Figure IV-30: Share of Affordable Block Groups by Neighborhood Type and Income Level
Note: HAMFI: HUD Area Median Family Income.

The dynamic relationships between housing and transportation costs on the one hand, and income on the other hand, produce different levels of affordability at different neighborhood types and for different income levels (Figure IV-30). The majority of block groups across all neighborhood types have housing and combined housing and transportation costs that are affordable to households earning 80% or more of the area median income. On the other hand, the share of block groups with affordable transportation costs decreases with distance from a rail station and the CBD. This trend in transportation affordability seems to stem from the higher transportation costs in non-rail and auto-oriented suburban neighborhoods.

Very and extremely low-income households, on the other hand, have only a small share of block groups that are affordable to them (Figure IV-30). Again, rail-proximate and pedestrian-friendly neighborhood types have a higher share of location-affordable block groups, mainly as a result of higher shares of transportation-affordable block groups due to higher levels of transit job accessibility. Consequently, transit-oriented development is the neighborhood type with the largest share of block groups that have combined housing and transportation costs that are affordable to the household at 50% of area median income, followed by non-rail pedestrian-friendly and rail-oriented intermediate development. Yet, less than two-percent of block groups in each neighborhood type are affordable to the household at 30% of area median income.

4.4.4. Summary

The results on housing and transportation affordability largely support the arguments stated in Hypothesis 4. Specifically, rail-proximate and pedestrian-friendly neighborhoods tend to be more affordable than lower-density and auto-oriented neighborhoods. These outcomes are mainly due to the lower transportation costs in transit-rich neighborhoods, while housing costs in these neighborhoods tend to be higher than in their non-rail counterparts. Moreover, housing cost burdens in transit-rich neighborhoods are somewhat moderated by the share of housing units in rail-oriented intermediate and non-rail pedestrian-friendly development. This suggests that housing in transit-rich neighborhoods might be more affordable in metropolitan areas with a larger diversity of neighborhood types while in more homogenous metropolitan areas induced demand for transit-rich neighborhoods keeps the cost burdens associated with neighborhoods higher.

However, while transportation cost burdens vary more than housing cost burdens and are considerably lower in transit-rich neighborhoods, they also seem to be a larger barrier toward housing and transportation affordability. This is because many households in transit-rich neighborhoods still own a private vehicle. As a result, only a small share of neighborhoods of all types are affordable to households earning 50% of area median income.

CHAPTER V

V. Discussion

In this dissertation I examined housing and transportation costs and affordability in U.S. metropolitan areas with intra-urban rail systems. The objective of the study was to understand whether neighborhoods near rail service are affordable, especially to lower-income households. The results of the study indicate that the majority of neighborhoods in the sampled metropolitan areas are affordable to median and moderate-income households earning 80% or more of area median income. Moreover, transit-rich neighborhoods are found to be more affordable than auto-oriented neighborhoods, mainly thanks to lower transportation costs. Still, only small share of neighborhoods is affordable to households earning 50% or less of area median income. The unaffordability of neighborhoods seems to be a function of high transportation costs but also of lower incomes.

5.1. Housing Supply and Housing Costs

The ability to afford housing, transportation, and other necessary services is an acute problem in the United States. Between 1980 and 2017 median gross rent in U.S. metropolitan areas with intra-urban rail service increased, on average, by thirty-seven percent. As a result, the share of neighborhoods with housing costs that are considered affordable has decreased over the last four decades. The housing affordability crisis is especially severe for lower-income households. For households earning 50% or less of their area's median income, the cost of living is considered affordable in only a small share of neighborhoods.

There is general agreement that the roots of the housing crisis are in the undersupply of housing, in part due to constraining land-use regulation, especially in high demand regions and neighborhoods. The results in this dissertation tend to support this understanding, showing that regions with more stringent land-use regulations are associated with higher housing costs. In addition, several "superstar cities" like San Francisco or Los Angeles, experienced large increases in housing costs alongside slow increases in housing supply. In these regions, there seems to be at least an anecdotal relationship between an undersupply of housing and higher housing costs.

The debate over the solutions to the housing affordability crisis, on the other hand, revolves around several, often conflicting, perspectives. Stemming from the identification of the housing affordability problem as an issue of housing supply, the main approach toward reducing housing cost burdens includes reforming land-use regulations, like single-family zoning, which constrain housing development in high-demand areas. Notable examples of this approach include Minneapolis and Oregon, which advanced measures that aim to promote housing development by eliminating single-family zoning. The underlying logic of this approach is that increasing the supply of market-rate housing will reduce prices and cost burdens by alleviating the demand for housing and allowing older housing units to filter down to lower-income households.

Within the affordability debate, special attention is often given to housing and transportation integration. In an effort to promote transit use and improve affordability, transportation and housing advocates call for providing more housing opportunities along transit-rich corridors. The California legislature, for example, attempted to pass a state bill that would have removed single-family zoning from transit-rich corridors to allow increasing housing densities. Even if housing near rail stations is expensive, say supporters, the neighborhood may still be affordable if households reduce transportation costs by using transit. Additionally, to the extent that housing near rail is expensive due to its limited supply regionwide, increasing its supply will reduce housing costs.

On the other hand, community members and affordable housing advocates often voice their doubts that increasing the supply of market-rate housing, including in transit-rich neighborhoods, can alleviate housing cost burdens. These 'supply skeptics' argue that market-rate housing will not reduce housing costs for lower-income households since older housing units do not filter down at a sufficient rate. In addition, new development might induce demand for more housing rather than alleviate demand pressures, thus leading to higher costs (Been et al., 2019). Instead, stakeholders call for housing solutions that specifically target lower-income households, for example, by increasing the supply of affordable housing units and providing rent assistance in the form of housing subsidies and vouchers.

The debate over housing costs, however, tends to treat housing as a single market. This one-dimensional perspective may lead to broad-stroke policies that might fail to fully address housing need and affordability. According to the single-market view, increasing the supply of housing should reduce housing costs regardless of where in the metropolitan area housing is supplied or the type of housing that is supplied. When distinctions between housing types are made, they are typically broad, mainly distinguishing between areas within a metropolitan area with higher and lower densities or between housing within or outside of transit-rich corridors.

Still, a wider classification of housing sub-markets may also be useful for characterizing the demand for housing and estimating the effects of supply changes on housing costs within metropolitan areas. Even near rail, neighborhoods vary in their built-environment characteristics, the types of housing they offer, their non-housing and transportation services, and housing costs that are related to these and other factors. Hence, the demand for housing in one sub-market may vary from the demand for housing in another sub-market and this variation would affect prices in each sub-market.

The analysis of housing costs in six neighborhood types produces results that support the arguments of both supply “enthusiasts” and “skeptics.” The results support the arguments made by supply skeptics, showing that even after controlling for metropolitan population, a larger ratio of housing units to population in a metropolitan area or the supply of housing units in transit-oriented development, the two measures of supply that receive the most policy attention, are associated with higher, rather than lower, housing costs. Since the supply of housing in TODs is limited at the metropolitan level, increasing the supply of housing in these neighborhoods cannot, on its own, meet all the demand for housing. Instead, the outcome is a process of induced demand, according to which an increase in supply attracts more demand rather than satisfying pre-existing demand. As a result, rather than costs decreasing, demand for TOD remains high as more housing units are supplied, thus keeping costs high as well. Reducing housing costs under these conditions is a pretty hefty task given current restrictive land-use regulations and housing shortages. Moreover, since most metropolitan areas have a small number of rail stations in areas that are potentially suitable for TODs, there is also a cap on the number of housing units that can be supplied in these neighborhoods. Thus, housing in TODs is also constrained by the number of rail stations, especially in the more central areas of a metropolitan area.

At the same time, the results also support the arguments made by supply enthusiasts, showing that a larger supply of housing in neighborhoods that can serve as alternatives to TODs is associated with lower housing costs in TODs. This implies that in regions with a larger supply of housing in different types of neighborhoods, households have a greater ability to locate in the type of neighborhood that better meets their housing preferences. The sorting of households based on their housing preferences reduces the demand for each type of neighborhood, thus moderating the housing costs in each neighborhood type. While TODs offer high levels of transit accessibility in a pedestrian-friendly built-environment, many households might be more interested in one of these characteristics than the other. Hence, households that prefer better accessibility but are indifferent to a pedestrian-friendly environment can locate in rail-oriented intermediate development. On the other hand, households that are interested in a pedestrian-friendly environment but are indifferent to levels of accessibility might locate in non-rail pedestrian-friendly neighborhoods. As the process of sorting occurs, only households with a preference for both accessibility and walkability will aim to locate in TODs, thus reducing the demand for, and therefore also housing costs in, this type of neighborhood.

These outcomes should not discourage housing policy makers from increasing the supply of housing in TODs. The higher housing costs in these neighborhoods suggest that there is still an unmet demand for housing in them. Yet the results also imply that targeting transit-oriented development might not be enough to solve the housing affordability crisis. Instead, housing policy should advance the development of neighborhoods that provide different amenities, including different built-environments and levels of accessibility. Providing a diverse set of neighborhoods for households to choose from allows households to sort by neighborhoods according to their preferences. This process reduces the demand for any specific type of neighborhood, thus leading to lower housing costs across all neighborhood types.

5.2. Location Affordability: The Housing- and Transportation-Cost Tradeoff

Another common solution to the current affordability crisis is to provide households with the opportunity to reduce transportation costs by providing transit and encouraging its use. As the second-highest cost-element in most households' budget, transportation costs are considered as an alternative to housing costs as a target for reductions and savings. While housing may be regarded as unaffordable on its own, a location might still be affordable if transportation costs are sufficiently low. In some cases, policy aims to achieve this by providing more housing along transit-rich corridors. In other cases, transportation planners aim to extend transit service into lower-income neighborhoods to allow reducing transportation costs by removing the need for a private vehicle. On the other hand, community residents and leaders often raise their concerns that transportation benefits increase housing costs above and beyond transportation-cost savings, thus reducing location affordability (Lung-Amam et al., 2019).

Again, the results in this dissertation back the arguments made by both housing-transportation-cost tradeoff enthusiasts and skeptics. On the one hand, the transportation-cost savings in transit-rich neighborhoods seem to be larger than the housing-cost appreciation in these neighborhoods. The housing costs that are associated with neighborhood types relative to auto-oriented development largely stem from their accessibility benefits, while neighborhood types are still associated with lower transportation costs after accounting for accessibility. Notably, the transportation-cost savings that are associated with transit job accessibility are nearly double the housing-cost appreciation that is associated with transit accessibility. And the decrease in the transportation-cost burden that is associated with accessibility is roughly triple the housing-cost burden increase that is associated with accessibility. As a result, as previous research has found (Renne et al., 2016), transit-rich and rail-proximate neighborhoods tend to be more affordable than less accessible and non-rail neighborhoods.

Yet, lower transportation costs and cost burdens do not necessarily mean affordable transportation costs or affordable neighborhoods, especially to lower-income households. Not only do transportation costs not moderate neighborhood cost burdens, for lower-income households they seem to exacerbate them. The urban form of most U.S. metropolitan areas and the suburbanization of employment opportunities since the 1960s and 1970s means that many households, including in central locations and transit-rich neighborhoods, still require a private vehicle to access employment and other necessary destinations (Grengs, 2010; Smart & Klein, 2017). Auto ownership is especially important for enabling lower-income households to maintain steady employment (Smart & Klein, 2018). As a result, even in the most transit-rich neighborhoods, and among the lowest-income neighborhoods, a large portion of households still owns a private vehicle and transportation costs exceed their affordability threshold.

But even if transportation costs were reduced to zero, most neighborhoods would still be unaffordable to households earning 50% or less of area median income because of severe housing cost burdens. Although housing costs in lower-income neighborhoods are relatively low because of smaller, older, and lower-quality housing, for lower-income households the majority of low-cost neighborhoods of all types would still be considered unaffordable. This implies that reducing transportation costs by providing transit cannot, on its own, solve neighborhood affordability problems. Helping lower-income households reduce location cost burdens also requires providing housing assistance, for example, through more affordable housing or rent assistance.

One way lower-income households may still overcome neighborhood unaffordability is locating in neighborhoods that have lower housing costs but still offer high levels of accessibility. Two types of neighborhoods seem meet these criteria – rail-oriented pedestrian-friendly neighborhoods and rail-oriented intermediate development. These neighborhoods enable households to minimize their transportation costs by offering relatively high levels of transit accessibility. At the same time, housing in these neighborhoods is less expensive than in TODs since it is farther from the CBD and it does not include TOD's walkability benefits or high shares of new housing units. As a result, households that reduce their transportation costs below the neighborhood average may find these neighborhoods more affordable than in other neighborhoods.

Evidence of this process can be found in Los Angeles and Portland, although the mechanism of the process in each MSA is different. The Los Angeles example shows that rail service enables lower-income households to remain in their community despite increasing housing costs. In Los Angeles, the opening of the Blue Line between downtown Los Angeles and Long Beach to the south in 1990 introduced light rail service to low-income communities like Compton and Watts and enabled their residents to reduce their transportation costs even at a farther distance from the CBD (Figure V-1). These communities have maintained their lower-income status over time and housing has remained relatively affordable. At the same time, the light rail line has enabled households to reduce transportation costs by moving to more suburban locations and relying on transit for commute purposes. As a result, areas as far as 10-15 miles south of downtown Los Angeles have remained relatively affordable, at least to households earning 80% or more of the area median income who rely on transit.

The Portland case shows that rail service can also help lower-income households find affordable neighborhoods once their original neighborhood becomes unaffordable. Previous research suggested that opening the light rail line to neighborhoods to the north of downtown Portland contributed to the increase in housing costs in these neighborhoods and the relocation of lower-income households eastward toward the city of Gresham (Goodling et al., 2015). This process is also evident from mapping the location of lower-income neighborhoods over time

(Figure V-2). Yet examining this process alongside the evolution of light rail and the change in housing cost burden in the region suggests that rail is also a consideration in what neighborhoods to relocate to.

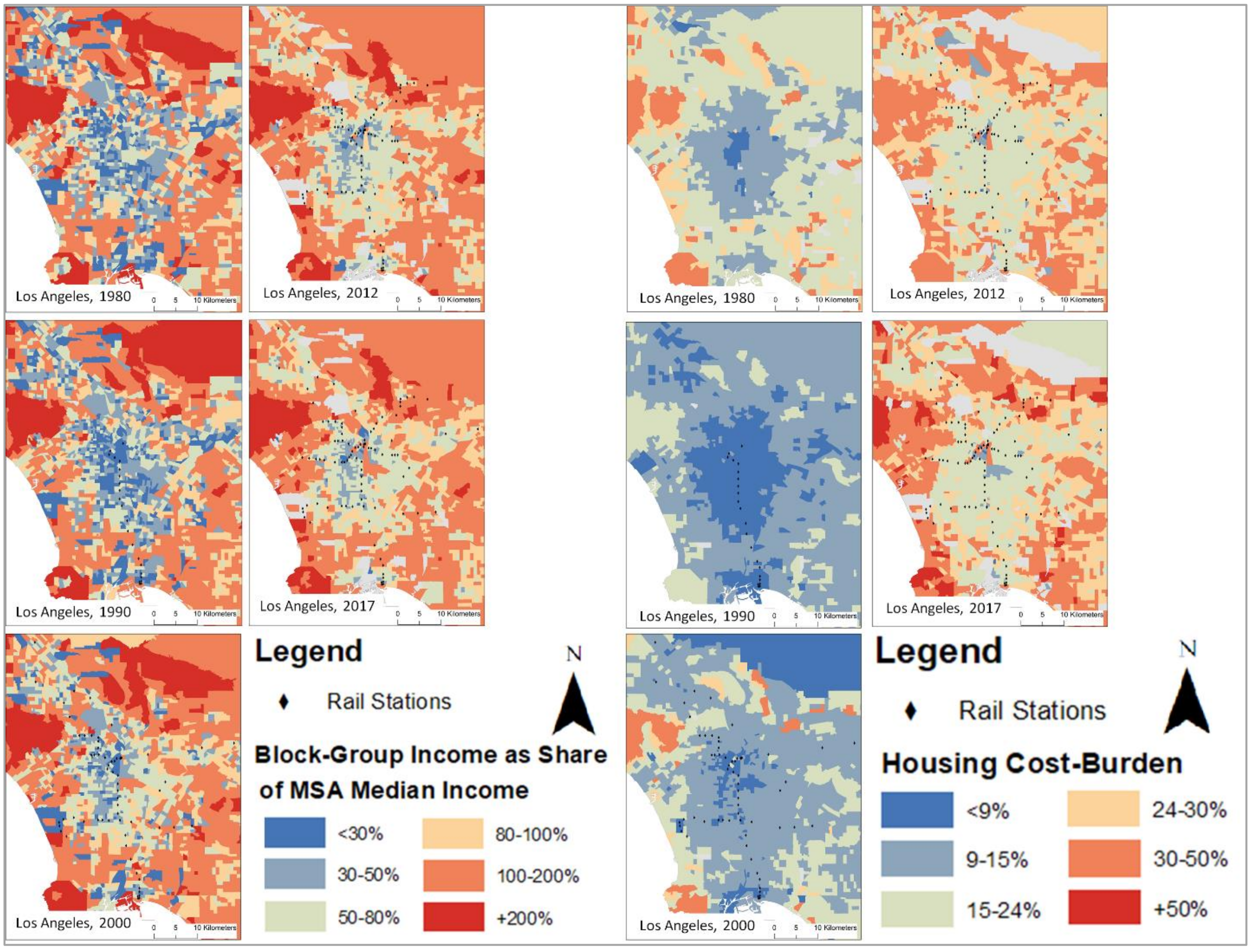

Figure V-1: Change in Neighborhood Income Level and Housing Cost Burden in Los Angeles, 1980-2017

Note: Cost-burden levels are based on area median income. Neighborhoods with a cost burden below 9% of AMI are affordable to households earning 30% or more of AMI; neighborhoods with a cost burden between 9-15% of AMI are affordable to households earning 50% or more of AMI; neighborhoods with a cost burden between 15-24% of AMI are affordable to households earning 80% or more of AMI; neighborhoods with a cost burden between 24-30% of AMI are affordable to households earning AMI or higher.

In 1980, neighborhoods just north of downtown Portland were predominantly lower-income. But incomes in these neighborhoods have increased over the years, with the development of the light rail system. During the same time period, areas along the Blue light rail line from downtown Portland eastward to Gresham have gained lower-income households (Figure V-2; Goodling et al., 2015; McKenzie, 2013). These eastward areas are characterized by rail-oriented intermediate neighborhoods, which are associated with relatively low housing costs. Hence, to the extent the locating along the light rail line allows households to reduce their transportation costs, moving eastward and farther away from downtown Portland enabled lower-income households to find affordable neighborhoods.

The examples from Los Angeles and Portland suggest that while more central transit-rich pedestrian-friendly neighborhoods become less affordable due to low housing supply, growing demand, and walkability benefits, rail service produces affordable locations farther from the CBD by extending accessibility benefits to new communities. The Portland example also suggests that, in some cases, the higher levels of accessibility and lower transportation costs that rail provides farther from the CBD might also explain the suburbanization of lower-income households in the region. In other words, rail-station areas farther from the CBD provide lower-cost single-family housing alternatives to the more central TOD neighborhoods while still maintaining high levels of transit accessibility and therefore also transportation affordability.

Hence, rail service has a dual effect on the location decisions of lower-income households. For one, rail service that allows reducing transportation costs increases the number of neighborhoods that are affordable to lower-income households that face unaffordability problems in their current neighborhood. At the same time, rail service into more suburban locations also allows lower-income households with a preference for single-family housing to find affordable neighborhoods that meet their preferences.

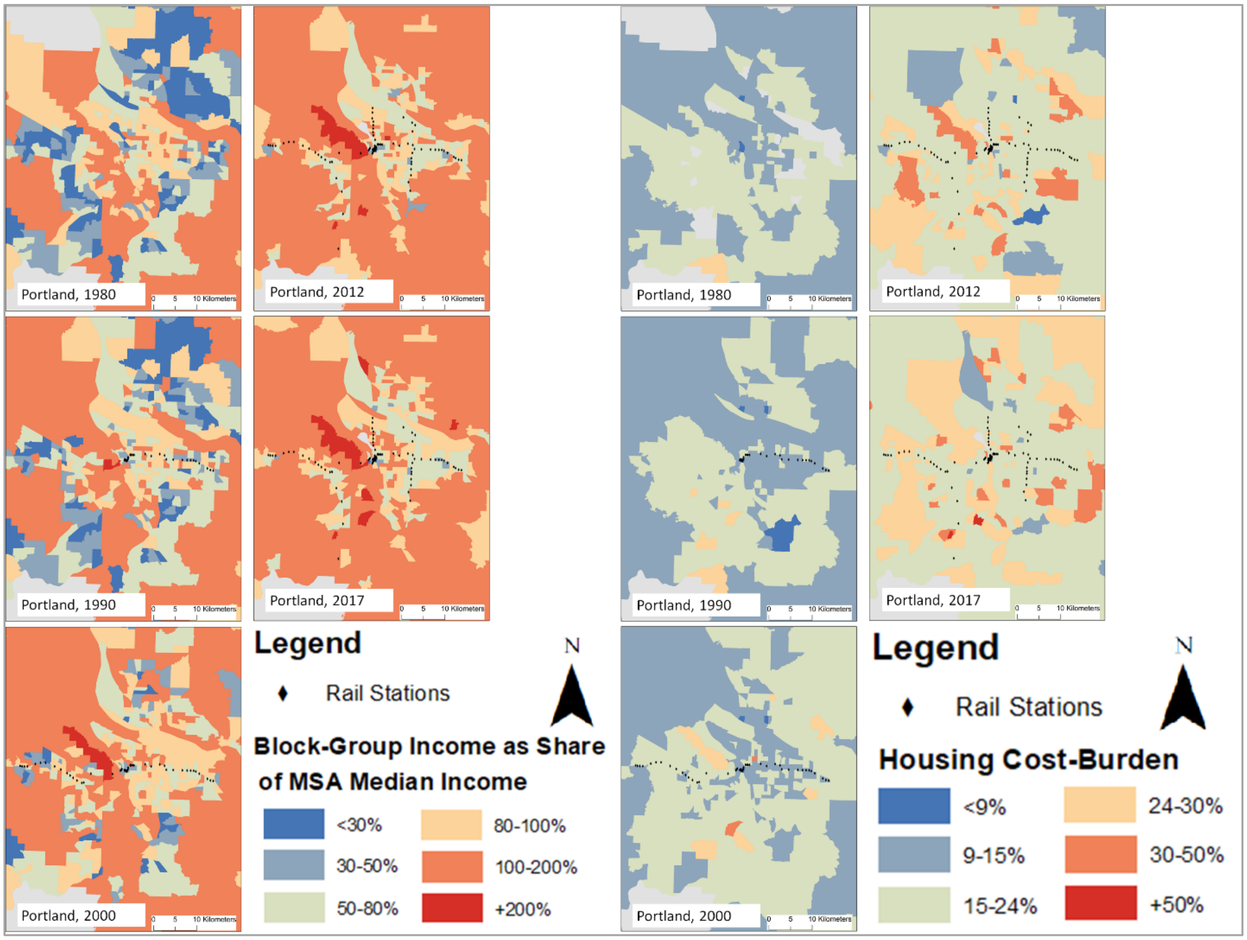

Figure V-2: Change in Neighborhood Income Level and Housing Cost Burden in Portland, 1980-2017

Note: Cost-burden levels are based on area median income. Neighborhoods with a cost burden below 9% of AMI are affordable to households earning 30% or more of AMI; neighborhoods with a cost burden between 9-15% of AMI are affordable to households earning 50% or more of AMI; neighborhoods with a cost burden between 15-24% of AMI are affordable to households earning 80% or more of AMI; neighborhoods with a cost burden between 24-30% of AMI are affordable to households earning AMI or higher.

From a policy perspective, the Los Angeles and Portland examples highlight the importance of extending transit service to wider areas of a metropolitan area as well as of increasing the supply of housing in a range of neighborhood types. Increasing the transportation alternatives that are available in suburban locations increases the number of neighborhoods that are affordable to lower-income households. From a housing policy perspective, these examples provide additional justification for increasing the supply of housing in rail-oriented intermediate and non-rail pedestrian-friendly neighborhoods rather than focusing development efforts only on gold-standard TODs. These alternative neighborhoods are associated with housing densities and levels of accessibility that are relatively similar to those in TODs. However, housing in these neighborhoods is less expensive because they do not include the walkability benefits increase housing costs in TODs. Therefore, increasing the supply of these alternative neighborhoods would provide additional affordable housing opportunities to lower-income households.

5.3. Income and Affordability

The findings in this dissertation support the findings of previous studies, showing that housing costs have increased over the past four decades. These cost increases are, to some degree, because of restrictive land-use regulations that create housing supply shortages in high-demand areas (Levine, 2010). Given these processes and their outcomes, it is understandable that solutions to the affordability crisis also focus on housing. Yet the focus on housing-market dynamics as the main source of and the main solution to the affordability crisis also fails to acknowledge the role that income plays in shaping affordability. Housing costs are only one part (the numerator) of the cost-burden equation, the other part (the denominator) being income. Indeed, several studies identify changes in income as a barrier to affordability (Feldman, Tyndall, Stern, Stackhouse, & Swan, 2002; Linneman & Megbolugbe, 1992; Myers & Park, 2019; Quigley & Raphael, 2004; Rodríguez-Pose & Storper, 2019). Still, the majority of studies explain housing cost burdens as a factor of changes in housing supply and its effect on costs. These studies either ignore or at least discount the role of income in the affordability crisis.

Income is related to affordability in several ways, but only the first has received considerable attention in the literature. The prevalent discussion on housing affordability treats income as a characteristic that distinguishes between population groups rather than as a factor explaining cost burden. According to this view, housing has become less affordable over time mainly due to supply shortages that make housing more expensive. And this process affects lower-income households more than higher-income ones since supply shortages at all income levels eventually limit the supply of mainly low-cost housing. Understood in this way, housing is unaffordable to lower-income groups because rents are high. Accordingly, if housing is unaffordable because it is undersupplied, eliminating restrictive land-use regulations and increasing the supply of housing should solve the housing affordability crisis, including for lower-income households.

Indeed, housing shortages seem to explain the high housing costs in a subset of metropolitan areas as well as in transit-oriented development. Housing in superstar MSAs like San Francisco, San Jose, and Los Angeles is expensive, to a large degree, because housing supply has been lagging behind demand for several decades. Similarly, housing in superstar neighborhoods like transit-oriented development is expensive, in part, because of its scarcity regionwide. Reducing costs and improving affordability in these high-demand metropolitan areas and neighborhoods will, therefore, require increasing the supply of housing in these areas as well as in alternative ones, especially rail-oriented intermediate and non-rail pedestrian-friendly development.

But housing costs and affordability are not just a factor of housing supply. In a large portion of MSAs, the slow increase in housing units over the years does not seem to be associated with higher housing costs or cost burdens. In these MSAs, two opposite trends, one in the housing market and one in the labor market, might also be contributing to the affordability crisis, especially among lower-income households. On the one hand, housing has become more expensive because higher-quality housing has filtered down to lower-income groups. At the same time, the purchasing power of many households has decreased because incomes have been stagnant and even declining.

In both cases, unaffordability is a product of low incomes rather than imperfections in the housing market.

The housing affordability crisis can be said to stem from housing-market imperfections if housing costs are expensive relative to the value of the physical structure of a home (Glaeser & Gyourko, 2003). Similarly, housing may be expensive due to planning imperfections such as land-use regulations that restrict the supply of housing to single-family housing (Levine, 2010). The results in this and in other studies suggest that land-use regulations, and especially those that limit the supply of multi-family housing, are associated with higher housing costs (Glaeser & Gyourko, 2002; Quigley & Rosenthal, 2005). On the other hand, the results here and elsewhere also suggest that housing costs in most MSAs are not necessarily higher because of housing supply shortages (Gyourko, Mayer, & Sinai, 2013), implying that costs mainly represent the value of the physical structure of a home (Glaeser & Gyourko, 2003).

One reason why housing may still be unaffordable to lower-income households might be quality improvements to the housing stock. Housing standards have increased over the years due to regulatory requirements on size, building materials, and necessary facilities and amenities. Hence, in many cases, the housing units that filter down to lower-income households might be of better quality than the housing units low-income households currently occupy. To the extent that quality improvements increase housing costs, the housing that is available to lower-income households might be less affordable even where costs do not exceed the value of the structure (Malpezzi & Green, 1996). Consequently, lower-income households struggle to find adequate housing that is also affordable (Lerman & Reeder, 1987; Thalmann, 1999; Tremoulet et al., 2016).

But another reason for housing being unaffordable to lower-income households is that their incomes have not changed at a similar rate as housing costs. While real housing costs have increased, among other things because of inflation, quality improvements, and supply shortages, incomes have not followed suit, especially at the lower end of the income distribution. Between 1980 and 2017, real income in U.S. metropolitan areas with intra-rail service increased, on average, by just fourteen percent compared to a thirty-seven percent increase in rent. This represents a relatively moderate increase in rent (of one-percent a year) but an even slower change in income. More importantly, between 2000 and 2017, real income in the sampled MSAs decreased by more than four percent while rent increased by more than fourteen percent. Consequently, households have less disposable income and housing cost burdens increase even in MSAs like Atlanta and Cleveland, where rents actually decreased.

The result is an increasing affordability problem, though one that also stems from lower incomes rather than only from housing-related factors. Lower incomes are partly due to shifts in the national and global economy (Wilson, 2012). At the national scale, low-skilled good-paying jobs are often found in small and medium-size cities rather than in larger metropolitan areas like the ones in this study (Porter, 2019; Porter & Gates, 2019). Similarly at the global scale, incomes for low-skilled jobs in traditionally industrial nations have remained low as adequate job opportunities relocated to developing nations (Linneman & Megbolugbe, 1992).

To the extent that the housing and location affordability problems among lower-income households stem, in part, from labor-market conditions, housing and transportation solutions might not be enough to completely solve the affordability crisis. Even if lower-income households reduced their transportation costs to a minimum by locating in rail-oriented intermediate development, a neighborhood type that offers similar levels of transit job accessibility as TODs but lower housing costs, very low-income households will still be cost burdened in most neighborhoods.

These outcomes imply that policy solutions should not only focus on reducing housing and transportation costs but also on helping lower-income households access and retain better-paying jobs. In the realm of housing, this might mean increasing affordable housing options closer to employment centers to minimize the mismatch between employment and housing locations (Kain, 1968, 1992). Transportation wise, this might mean helping lower-income households access and retain auto ownership, which is crucial for accessing employment opportunities (Grengs, 2010) and retaining employment status (Smart & Klein, 2018). Finally, policy should also focus on non-housing or transportation solutions. For example, providing job-training programs to lower-skilled workers to help them develop the necessary skills for participating in the service- and technology-oriented economy.

CHAPTER VI

VI. Conclusions

Housing affordability is a major problem in U.S. metropolitan areas, especially for lower-income households. Within the affordability debate, public transport is often discussed as both a contributor to the affordability problem and as a potential solution to it. On the one hand, housing near transit stations that offer access to employment and other necessary destinations is often more expensive due to these transportation benefits. On the other hand, the same transportation benefits also allow reducing transportation costs by relying on transit, thus potentially keeping a location affordable. In this dissertation, I address these issues and study housing and transportation costs and affordability in neighborhoods near and away from rail stations in 27 metropolitan areas in the U.S. In doing so, I emphasize how costs and affordability vary within metropolitan areas between neighborhoods with different built environments. The results contribute to discussions on the relationships between transportation benefits and neighborhood built environment on the one hand and housing and transportation costs and affordability on the other hand.

The longitudinal analysis of housing costs between 1980 and 2017 shows that median gross rent increased over time, though the rate of change was higher in high-demand metropolitan areas and neighborhood types. At the neighborhood level, these differences stem, to a large degree, from the transportation characteristics of a neighborhood. Notably, rent in rail-proximate neighborhoods increased at a higher rate than in their non-rail counterparts. The more nuanced cross-sectional analysis supports the longitudinal findings, showing that rent tends to be higher in neighborhoods that are within walking distance from a rail station when compared to their non-rail counterparts.

In addition to transit-accessibility rent premiums, the analysis also identified a built-environment premium or an induced demand effect that is capitalized in transit-oriented development housing markets. Specifically, housing costs in TODs remain high even after accounting for transit accessibility, suggesting that at least part of the higher costs in these neighborhoods stem from their built environments and the demand for them. This outcome implies that the combinations of housing density, walkability, and the development of new housing units in TODs create a unique housing market that is demanded by the public.

From a policy perspective, these outcomes are typically regarded as a benefit since higher property values and rents can generate additional financial municipal resources. By taxing the increases in property values and rents, either through existing property taxes or project-specific taxes, a municipality can increase its revenue from a new rail project or neighborhood uplift. These additional funds, in turn, can be directed to partly fund the transportation project. Alternatively, these resources can be directed to develop affordable housing units or provide rent assistance in transit-rich neighborhoods, where residents often fear that an increase in housing costs will price them out of their neighborhood.

On top of rent premiums from transportation benefits and the built environment, the high housing costs in transit-oriented development also stem from the scarcity of these neighborhoods regionwide. Despite growing demand for compact and pedestrian-friendly development in recent decades, land-use regulations and local opposition frequently curtail the short- and long-run supply of housing in transit-rich and pedestrian-friendly neighborhoods. Notably, land-use regulations that delay and even prevent the construction of multi-family housing units are found here to be associated with higher housing costs, especially in dense and walkable neighborhoods. These outcomes suggest that loosening regulation to allow the development of multi-family housing regionwide might reduce the rent premiums that are associated with housing in TODs and other neighborhood types.

Along the same lines, if rents in TODs are high because of a housing shortage, it can be expected that a larger supply of housing in these neighborhoods will be associated with lower rents. However, the analysis here shows that a larger share of housing units in TODs at the metropolitan level is associated with higher, rather than lower, housing costs in TODs as well as in other neighborhood types, even after controlling for the size of the MSA. These results suggest that induced demand for neighborhoods that offer pedestrian-friendly environments and proximity to transit prevents housing costs from decreasing when housing units in these built environments are supplied only in TODs.

At the same time, larger shares of housing units in non-rail pedestrian-friendly development and especially in rail-oriented intermediate development moderate the housing-cost premiums in TODs and in other neighborhood types. These outcomes suggest that these neighborhoods serve as alternatives to TODs. As such, a larger supply of housing in these neighborhoods helps moderate housing costs in TODs by allowing to separate the demand for TODs from the demand for a pedestrian-friendly environment regardless of rail or the demand for rail regardless of walkability.

Combined, the results on housing costs imply that, in order to reduce housing costs by increasing housing supply, planning agencies and municipalities should focus their efforts on developing a diverse set of neighborhood types rather than putting all their eggs in the 'TOD basket.' Given current housing shortages in high-demand regions, the geographic constraints put in place by the limited number of rail stations in an MSA, and barriers to densification such as land-use regulation and local opposition, it is unlikely that providing more housing along transit corridors will be enough to meet current and future demand. A more diverse range of neighborhoods is therefore needed, in which each neighborhood type offers a different set of local amenities, both near and away from rail.

Achieving this goal requires a metropolitan-wide effort in which a large number of municipalities loosen land-use regulation to support denser and mixed-use development across a metropolitan area. However, given the decentralized structure of regional decision making in the U.S., land-use regulation changes might be more effective coming from the state level. The City of Minneapolis, for example, approved a measure that eliminates single-family zoning and promotes mixed-use development in its jurisdiction to promote compact and walkable environments across the city. While this is a necessary step in increasing the supply of housing across a diverse range of neighborhoods, it might only have a limited effect if other municipalities in the region do not follow suit. Alternatively, Oregon recently passed a measure to allow developing duplexes and denser development in areas defined as single-family zoning in cities with more than 10,000 residents or within metropolitan areas. Yet the Oregon bill does not include elements to promote mixed-use neighborhoods through the development of commercial and retail properties in residential zones. As a result, the effect of the bill might be the densification of neighborhoods but not necessarily increasing the number of walkable destinations in them. It remains to be seen how the State Bill will shape the urban form in cities across the state, and especially in the Portland metropolitan area.

Whereas housing in rail-proximate neighborhoods tends to be more expensive than in their non-rail counterparts, transportation costs in these neighborhoods are estimated to be lower than in neighborhoods farther from a rail station. The major factor contributing to this distribution of transportation costs is the level of transit job accessibility in a neighborhood, which tends to be higher in areas that are served by rail or effective bus service. The analysis further shows that, where transit accessibility is high, residents are less likely to own a private vehicle and more likely to use transit as their main commute mode, even after controlling for neighborhood socio-demographic factors. These results imply that improving transit accessibility, especially through rail but also through bus service, can be an effective approach for helping households reduce their transportation expenses by substituting auto ownership and use with transit use.

6.1. Neighborhood Affordability: Implications to Housing and Transportation Policy

Analyzing housing and transportation costs identified a housing - transportation cost tradeoff according to which neighborhoods with lower transportation costs are also associated with higher rents. Still, a question remains about the types of neighborhoods that are affordable to households with different income levels, and especially lower-income households. While transportation costs in transit-rich neighborhoods may be low, the higher housing costs might still prevent lower-income households from locating in these neighborhoods and benefiting from their transportation options. Analyzing neighborhood cost burdens reveals that affordability concerns are especially relevant to very low-income households, as only a small share of neighborhoods is affordable to these income groups. On the other hand, the majority of neighborhoods of all types are affordable to households earning at least eighty percent of area median income. The results from the location affordability analysis have implications for the types of housing and transportation policies that can improve affordability. Yet the analysis also highlights the limitations of such policies to provide a complete solution to current affordability problems.

Examining housing and transportation affordability across neighborhood types reveals that transit-rich locations tend to be more affordable than auto-oriented neighborhoods, despite having higher housing costs, thanks to the lower transportation costs. These outcomes suggest that the transportation-cost savings in transit-rich neighborhoods are larger than the rent premiums from transportation benefits, leading to lower overall neighborhood cost burdens. Accordingly, three types of neighborhoods stand out as being more affordable to lower-income households due to the ability to minimize transportation costs by relying on transit: transit-oriented development, non-rail pedestrian-friendly development, and rail-oriented intermediate development. These neighborhoods tend to be located closer to central business districts or along rail corridors and offer high levels of transit job accessibility through rail and bus service.

The results from the location affordability sections, together with the analyses of housing and transportation costs, highlight several housing- and transportation-related planning measures that have the potential to improve neighborhood affordability, including for lower-income households. Specifically, the analyses show that, in addition to promoting TOD development, planning agencies and municipalities should also focus efforts on increasing the supply of housing in rail-oriented intermediate development and non-rail pedestrian-friendly development. First, housing in these neighborhoods is more affordable than in TODs since they are not influenced by built-environment premiums or large demand pressures. Similarly, housing in these neighborhoods is more affordable than housing in suburban neighborhoods because of smaller housing units. In addition, these neighborhoods are also associated with relatively low transportation costs and cost burdens, especially for households that substitute auto ownership and use with transit. Finally, a larger share of housing in these neighborhoods at the metropolitan level is associated with lower housing costs and cost burdens in all neighborhood types.

Municipalities and planning agencies can promote the development of rail-oriented intermediate and non-rail pedestrian-friendly neighborhoods through housing, land-use, and transportation decisions. These neighborhood types are characterized by medium-high housing-unit densities and medium-high levels of walkability either near or away from rail. Hence, removing obstacles and providing incentives to transform single-family residential areas into more compact and walkable neighborhoods can promote the development of a wider range of neighborhood types. Specifically, housing and land-use planners should loosen housing, commercial, and retail land-use restrictions to permit multi-family housing and mixed-use development across a metropolitan area and especially in areas with single-family housing. Such efforts will allow denser and more diverse urban forms where there is demand for it. To this end, efforts could also focus on single-family neighborhoods along rail and bus corridors to extend development farther out from the center of metropolitan areas.

At the same time, transportation planners can promote the development of rail-oriented intermediate and non-rail pedestrian-friendly neighborhoods through the extension of rail and bus (as a feeder mode to rail, for example) service into non-rail intermediate development and other lower-density auto-oriented neighborhoods. Non-rail intermediate neighborhoods share the same built-environment characteristics as rail-oriented intermediate development but enjoy much lower levels of transit job accessibility. As a result, auto ownership, and therefore also transportation costs, in these neighborhoods are relatively high, thus resulting in unaffordable cost burdens. Extending transit into these and other lower-density auto-oriented neighborhoods would allow residents to reduce transportation costs and improve location affordability by relying on transit. Moreover, improving transit service in low-transit neighborhoods would also provide incentives for more compact and mixed-use development in predominantly single-family neighborhoods, thus increasing the share of housing units in more compact and pedestrian-friendly environments.

Extending transit service farther out from the central business district is especially important for providing affordable transportation options to lower-income households. The suburbanization of lower-income households, in part due to increasing housing costs in central locations and in part due to a change in housing preferences, means that lower-income households are also becoming more auto dependent. The examples from Los Angeles and Portland, however, show that rail service in more suburban locations allows households to reduce their transportation costs by relying on transit. The result is rail-oriented intermediate neighborhoods that are affordable to lower-income households living farther from the CBD.

Finally, the analysis of housing and transportation costs and affordability also shows that in many MSAs, a major contributor to the affordability crisis is the slow and even stagnant change in income rather than only large increases in rents. If lagging incomes are indeed contributing to the current location affordability crisis, then policy and planning efforts using housing and transportation solutions may not be enough to alleviate location unaffordability. In addition to these efforts, municipal planners should also prioritize community development efforts that emphasize strengthening human and social capital. Providing a comprehensive basket of housing, land-use, transportation, and community-development approaches will tackle the affordability crisis from different angles, thus increasing the possibility of improving the livelihoods of city residents.

6.2. Future Research

The results in this dissertation and their implications to policy and our understanding of the relationships between transportation benefits, housing costs, and neighborhood affordability leave some questions unanswered and open new avenues for research. First, more research is needed that uses accessibility as the measure of transportation benefits that explain variation in housing costs near rail stations. The majority of studies on house prices and affordability near rail stations rely on distance to a rail station and the CBD as proxies for transportation benefits. The results in this dissertation and elsewhere (Ahlfeldt, 2011), however, reveal that these proxies might not capture the full effect that transit accessibility has on housing costs near rail stations. As a result, studies that use distance as a proxy for accessibility might underestimate the capitalization of transportation benefits in the housing market.

More research is also needed on the temporal relationship between when the transportation benefits from new rail service can be reaped and when these benefits capitalize in the housing market. In the long run, increasing housing density helps mitigate the higher housing costs that stem from transportation-cost savings following transportation improvements. However, speculations on house-price appreciation before rail service begins (Golub et al., 2012; S. Yan et al., 2012b) and the time it takes to develop new housing after rail service begins mean that, in the short term, housing-cost increases might be larger than transportation-cost savings. If housing costs increase before transportation costs decrease, and increase more than the decrease in transportation costs, lower-income households might be temporarily cost burdened, perhaps to the extent of pricing them out of the neighborhood.

One way lower-income households are able to afford to live in transit-rich neighborhoods is by locating farther from the CBD. The case of Portland shows that, as housing costs in central neighborhoods increased over time, concentrations of lower-income households moved from these areas eastward along the light rail line to more suburban locations. Previous research on the link between low-income households and transit typically focused on the negative effects of high housing costs on the ability of households to remain in their neighborhoods. At the same time, studies on the suburbanization of lower-income households have either ignored transportation as a factor in the relocation or as a negative outcome of relocation as households that move require a private vehicle to access necessary goods and services. More research is therefore needed that links the suburbanization of lower-income households to the availability of transit in inner-ring suburbs.

Closely related, more research is also needed on the characteristics of neighborhoods that serve as alternatives to transit-oriented development, such as rail-oriented intermediate development and non-rail pedestrian-friendly development. Transit-oriented development receives the majority of attention from planners and academics as the gold standard of urban neighborhoods with an ideal integration of housing and transportation. As such, it is also viewed as a potential solution to the unaffordability of housing since transportation costs can be minimized. However, because of the higher housing costs in these neighborhoods, other transit-rich neighborhoods might be more affordable to households that rely on transit for their transportation needs. In other cases, these neighborhoods might be more affordable to households that have a preference for a pedestrian-friendly urban form but are indifferent to the levels of transit accessibility in the neighborhoods. Thus, providing more housing opportunities in alternative neighborhoods moderates the housing costs in TODs by separating the demand for the combination of accessibility and walkability from the demand for only one of these elements. Despite the importance of these neighborhood types to meeting the demand for housing among different households, not enough is known about these neighborhoods, their characteristics, and the households that live in them.

APPENDECIES

Table VII-1: Land-Use Regulations Models; Dependent Variable: Annual Median Gross Rent (2019$)

VARIABLES	Wharton Index Coef. (Std Err)	Multi-Family Development Approval Time Coef. (Std Err)	Multi-Family Constraints Coef. (Std Err)
Block-group Level			
% Black	-11.288***	-12.122***	-12.106***
	(0.973)	(0.960)	(0.960)
% Hispanic	-20.648***	-19.774***	-19.807***
	(1.228)	(1.227)	(1.228)
% Age 25-39	33.508***	31.298***	31.525***
	(2.355)	(2.342)	(2.340)
Average Household Size	-94.843**	-85.456**	-85.625**
	(42.327)	(42.309)	(42.332)
% Small Housing Units	-47.043***	-47.539***	-47.617***
	(1.189)	(1.177)	(1.178)
% New Development	25.802***	25.980***	25.679***
	(1.388)	(1.373)	(1.374)
Median Household Income (1000s)	83.274***	84.264***	84.541***
	(0.912)	(0.903)	(0.901)
Median House Value (1000s)	1.734***	1.695***	1.689***
	(0.106)	(0.106)	(0.106)
Distance to Highway Ramp (Km)	-33.404***	-33.738***	-35.111***
	(11.150)	(11.199)	(11.190)
Distance to Rail (Km)	-3.069	-3.693	-5.272**
	(2.686)	(2.684)	(2.678)
Job Accessibility (1000s)	0.765***	0.843***	0.824***
	(0.055)	(0.058)	(0.056)
Neighborhood Type (Reference: Auto-oriented)			
Transit-adjacent	-648.401***	-536.295***	-514.185***
	(123.331)	(119.278)	(129.131)
Non-rail intermediate	-178.403***	-115.073**	-207.967***
	(50.744)	(53.475)	(51.761)
Rail-oriented intermediate	-216.005**	-143.649	-178.057*

	(95.634)	(97.410)	(96.377)
Non-rail pedestrian-friendly	-25.088	97.202	-20.994
	(84.005)	(100.703)	(87.705)
Transit-oriented	462.521***	692.872***	208.047
	(124.677)	(144.486)	(133.250)
Metropolitan Level			
Population	0.271***	0.139	0.241**
	(0.089)	(0.090)	(0.100)
Land-use Regulations (Reference: Auto-oriented)	1,381.231***	1,677.341***	1,053.738**
	(375.372)	(370.448)	(414.535)
Transit-adjacent	-379.846***	-345.157***	-308.011**
	(122.395)	(113.916)	(142.448)
Non-rail intermediate	-297.292***	-318.122***	-89.340
	(43.646)	(47.184)	(54.704)
Rail-oriented intermediate	-414.171***	-241.504***	-136.628
	(98.984)	(80.927)	(111.212)
Non-rail pedestrian-friendly	-504.402***	-454.639***	-306.800***
	(72.036)	(86.882)	(78.684)
Transit-oriented	-485.895***	-457.510***	543.122***
	(136.270)	(119.827)	(136.985)
Constant	9,783.227***	10,451.17***	9955.399***
	(588.858)	(562.08)	(642.852)
Observations	44,537	45,762	45,762
Number of groups	20	21	21
Wald	42390***	44234***	44152***
LR test	4255***	4546***	6068***

*** p<0.01, ** p<0.05, * p<0.1

Table VII-2: Neighborhood Housing Supply Models on Housing Costs. Cross-Sectional Analysis; Dependent variable: Annual Median Gross Rent (2019$)

	Housing Unit to Population Ratio	TOD Housing Unit Share	Pedestrian-Friendly Housing Unit Share	Rail Intermediate Housing Unit Share
	Coef.	Coef.	Coef.	Coef.
VARIABLES	(Std Err)	(Std Err)	(Std Err)	(Std Err)
Block-group Level				
% Black	-14.050***	-13.748***	-14.208***	-13.928***
	(0.866)	(0.870)	(0.866)	(0.867)
% Hispanic	-25.415***	-25.394***	-25.812***	-25.458***
	(1.098)	(1.105)	(1.099)	(1.099)
% Age 25-39	35.312***	37.279***	35.360***	36.352***
	(2.061)	(2.083)	(2.059)	(2.066)
Average Household Size	71.077*	45.348	81.948**	57.129

	(37.993)	(38.229)	(37.998)	(38.043)
% Small Housing Units	-39.145***	-38.899***	-39.058***	-38.940***
	(1.055)	(1.066)	(1.054)	(1.056)
% New Development	25.323***	25.740***	25.436***	25.471***
	(1.234)	(1.259)	(1.234)	(1.235)
Median Household Income (1000s)	94.105***	94.494***	93.827***	94.216***
	(0.735)	(0.740)	(0.735)	(0.735)
Neighborhood Type (Reference: Auto-oriented)				
Transit-adjacent	-1,156.486	-609.819***	183.839	-767.123***
	(871.247)	(183.184)	(210.989)	(166.234)
Non-rail intermediate	-1,257.212***	-227.516***	242.744***	-190.996***
	(360.307)	(65.294)	(85.396)	(60.597)
Rail-oriented intermediate	-1,465.078*	-774.960***	554.999***	-606.605***
	(756.105)	(151.855)	(167.130)	(133.644)
Non-rail pedestrian-friendly	127.389	-537.272***	779.715***	-358.198***
	(542.755)	(115.933)	(150.662)	(100.488)
Transit-oriented	1,211.185	-1,114.747***	921.181***	-47.830
	(878.997)	(232.862)	(222.637)	(182.817)
Distance to Highway Ramp (Km)	-31.935***	-37.318***	-29.691***	-34.287***
	(10.494)	(10.632)	(10.492)	(10.506)
Distance to Rail (Km)	-8.694***	-10.560***	-7.233***	-10.107***
	(2.247)	(2.280)	(2.255)	(2.254)
Job Accessibility (1000s)	0.849***	0.671***	0.855***	0.720***
	(0.045)	(0.050)	(0.045)	(0.051)
Metropolitan level				
% Housing Units (Reference: Auto-oriented)	-7,176.998	-103.478	287.924***	-201.331***
	(5,095.830)	(113.471)	(79.836)	(67.536)
Transit-adjacent	1,482.471	15.565	-100.499***	25.767*
	(2,213.178)	(27.532)	(24.984)	(14.276)
Non-rail intermediate	2,722.712***	18.935*	-51.575***	6.631
	(898.640)	(11.071)	(8.755)	(5.756)
Rail-oriented intermediate	3,293.586*	103.917***	-92.640***	41.450***
	(1,911.621)	(18.170)	(19.554)	(8.611)
Non-rail pedestrian-friendly	-526.087	93.537***	-90.172***	38.595***
	(1,342.823)	(16.929)	(13.024)	(8.469)
Transit-oriented	-1,915.409	210.671***	-54.120**	47.653***
	(2,228.457)	(25.523)	(23.035)	(11.018)
Population	0.119		0.220**	0.292***
	(0.075)		(0.095)	(0.086)
Median House Value (1000s)	12.818***	15.359***		13.289***
	(2.171)	(2.661)		(1.933)
Constant	8,989.114***	6,251.146***	7,429.785***	6,191.899***
	(2,221.888)	(751.075)	(719.729)	(602.890)
Observations	52,573	51,959	52,573	52,573

Number of groups	23	22	22	23
Wald test	54113***	53705***	54199***	54214***
Linear Regression test	4244***	4499***	5612***	3295***

*** p<0.01, ** p<0.05, * p<0.1

Table VII-3: Neighborhood Housing Supply Models, Longitudinal Analysis, Dependent Variable: Annual Median Gross Rent (1000s; 2019$)

	Housing Units per 100,000 Residents	% High-Density Rail Housing Units	% High-Density Non-Rail Housing Units	% Medium-Density Rail Housing Units
VARIABLES	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)
Block-group Level				
% Black	-0.030***	-0.029***	-0.030***	-0.0296***
	(0.0004)	(0.0004)	(0.0004)	(0.0004)
% Hispanic	-0.038***	-0.038***	-0.038***	-0.0381***
	(0.0005)	(0.0005)	(0.0005)	(0.0005)
% Age 25-39	0.079***	0.080***	0.075***	0.0764***
	(0.002)	(0.002)	(0.002)	(0.002)
% Small Housing Units	-0.041***	-0.041***	-0.041***	-0.0409***
	(0.0005)	(0.0005)	(0.0005)	(0.0005)
% New Development	0.034***	0.034***	0.035***	0.0348***
	(0.0006)	(0.0006)	(0.0006)	(0.0006)
Year (Reference: 2000)				
1980	2.237***	0.398***	0.556***	0.4711***
	(0.402)	(0.133)	(0.143)	(0.132)
1990	1.314***	0.315***	0.239**	0.2036**
	(0.394)	(0.099)	(0.109)	(0.102)
2012	1.894***	1.806***	1.912***	1.9168***
	(0.459)	(0.098)	(0.109)	(0.114)
2017	1.548***	1.161***	1.121***	1.384***
	(0.457)	(0.0992)	(0.110)	(0.118)
Median Household Income (1000s)	0.045***	0.045***	0.045***	0.0453***
	(0.0006)	(0.0006)	(0.0006)	(0.0006)
1980	-0.019***	-0.018***	-0.017***	-0.0183***
	(0.0009)	(0.0009)	(0.0009)	(0.0009)
1990	-0.011***	-0.012***	-0.011***	-0.0126***
	(0.0008)	(0.0008)	(0.0008)	(0.0008)
2012	0.012***	0.012***	0.012***	0.012***
	(0.0008)	(0.0009)	(0.0009)	(0.0008)
2017	0.044***	0.044***	0.044***	0.044***
	(0.0008)	(0.0008)	(0.0008)	(0.0008)
Distance from CBD (KM, 1000s)	-0.009***	-0.009***	-0.010***	-0.009***
	(0.0006)	(0.0006)	(0.0006)	(0.0006)
Neighborhood Type (Reference: Low Density Non-Rail)				

Low Density Rail	0.029	-0.532***	0.028	-0.144
	(1.042)	(0.155)	(0.267)	(0.277)
1980	-0.112	0.243	-0.569	-0.771
	(1.435)	(0.296)	(0.624)	(0.502)
1990	1.116	0.227	0.162	-0.295
	(1.148)	(0.248)	(0.461)	(0.461)
2012	-0.401	0.673***	0.139	0.384
	(1.485)	(0.210)	(0.350)	(0.375)
2017	-1.895	0.376*	0.220	0.276
	(1.476)	(0.209)	(0.344)	(0.373)
Medium Density Non-Rail	0.180	-0.068	0.529***	0.085
	(0.497)	(0.059)	(0.095)	(0.081)
1980	-0.597	0.017	-0.282*	-0.117
	(0.534)	(0.083)	(0.145)	(0.103)
1990	-1.185**	-0.118	-0.380***	-0.191*
	(0.523)	(0.081)	(0.134)	(0.107)
2012	1.072	0.297***	-0.109	0.064
	(0.673)	(0.084)	(0.130)	(0.125)
2017	-0.315	-0.036	-0.136	-0.375***
	(0.676)	(0.085)	(0.131)	(0.129)
Medium Density Rail	1.675*	-0.945***	0.010	-0.251
	(0.883)	(0.138)	(0.240)	(0.259)
1980	-1.941	0.473*	-0.295	-0.187
	(1.205)	(0.251)	(0.486)	(0.457)
1990	-2.811***	0.206	0.372	-1.041***
	(0.964)	(0.207)	(0.381)	(0.398)
2012	-0.155	0.756***	0.641**	-0.079
	(1.222)	(0.184)	(0.306)	(0.333)
2017	-2.362*	0.432**	0.319	-0.439
	(1.215)	(0.183)	(0.301)	(0.328)
High Density Non-Rail	1.058*	0.074	1.382***	0.471***
	(0.613)	(0.092)	(0.180)	(0.139)
1980	-3.149***	-0.120	-1.241***	-0.487***
	(0.684)	(0.124)	(0.273)	(0.169)
1990	-4.114***	-0.251**	-0.582**	-0.694***
	(0.659)	(0.123)	(0.249)	(0.177)
2012	-0.334	0.317**	-0.242	-0.236
	(0.865)	(0.127)	(0.244)	(0.206)
2017	1.425	0.013	0.219	-0.150
	(0.885)	(0.128)	(0.244)	(0.209)
High Density Rail	7.975***	-0.416***	2.677***	-1.049***
	(0.895)	(0.151)	(0.302)	(0.273)
1980	-5.954***	0.357	-0.943*	1.004**
	(2.018)	(0.245)	(0.546)	(0.424)
1990	-13.030***	0.854***	0.991**	-1.801***
	(1.109)	(0.227)	(0.483)	(0.409)
2012	0.085	0.437**	-0.281	0.308
	(1.276)	(0.203)	(0.391)	(0.367)
2017	1.276	0.254	0.394	1.309***

	(1.286)	(0.201)	(0.385)	(0.362)
Metropolitan Level				
% Housing Unit	0.00001	0.012	0.051***	-0.010
	(0.00001)	(0.015)	(0.011)	(0.013)
1980	-0.00004***	0.007	-0.031***	0.019
	(0.00001)	(0.006)	(0.007)	(0.014)
1990	-0.00003**	0.043***	0.025***	0.136***
	(0.00001)	(0.005)	(0.007)	(0.013)
2012	-0.000001	0.006	0.025***	-0.007
	(0.00001)	(0.005)	(0.008)	(0.015)
2017	-0.00001	-0.018***	0.018**	-0.033**
	(0.00001)	(0.005)	(0.008)	(0.0154)
Low Density Rail	-0.000008	0.018**	-0.026	-0.017
	(0.00003)	(0.008)	(0.018)	(0.037)
Medium Density Non-Rail	-0.000007	-0.003	-0.049***	-0.039***
	(0.00001)	(0.004)	(0.007)	(0.015)
Medium Density Rail	-0.00006***	0.025***	-0.046***	-0.044
	(0.00002)	(0.007)	(0.015)	(0.034)
High Density Non-Rail	-0.00003	0.006	-0.084***	-0.067***
	(0.00002)	(0.005)	(0.010)	(0.022)
High Density Rail	-0.0002***	0.039***	-0.141***	0.210***
	(0.00002)	(0.005)	(0.018)	(0.035)
Population (Mil.)	0.205***	0.287***	0.208***	0.327***
	(0.033)	(0.025)	(0.029)	(0.023)
1980	0.033***	0.047***	0.039***	0.048***
	(0.007)	(0.013)	(0.007)	(0.007)
1990	0.015**	-0.014	-0.0007	0.010
	(0.0073	(0.011)	(0.007)	(0.007)
2012	0.045***	0.031***	0.033***	0.040***
	(0.006)	(0.009)	(0.006)	(0.006)
2017	0.037***	0.037***	0.026***	0.030***
	(0.006)	(0.009)	(0.006)	(0.006)
Median House Value (1000s)	0.017***	0.017***	0.016***	0.017***
	(0.0004)	(0.0005)	(0.0004)	(0.0005)
1980	-0.007***	-0.007***	-0.006***	-0.007***
	(0.0005)	(0.0006)	(0.0006)	(0.0005)
1990	-0.001***	-0.001***	-0.002***	-0.002***
	(0.0003)	(0.0003)	(0.0004)	(0.0003)
2012	-0.007***	-0.007***	-0.008***	-0.007***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
2017	-0.007***	-0.007***	-0.007***	-0.007***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
% Housing Unit Interaction* Low Density Rail				
1980	0.00001	-0.004	0.064*	0.150**
	(0.00004)	(0.012)	(0.037)	(0.065)
1990	-0.00002	-0.009	0.023	0.054
	(0.00003)	(0.011)	(0.030)	(0.060)
2012	0.00001	-0.040***	-0.003	-0.038
	(0.00004)	(0.011)	(0.024)	(0.050)

2017	0.00005	-0.030***	-0.034	-0.055
	(0.00004)	(0.011)	(0.024)	(0.049)
% Housing Unit Interaction* Medium Density Non-Rail				
1980	0.00002	-0.001	0.030***	0.021
	(0.00001)	(0.006)	(0.009)	(0.021)
1990	0.00002	-0.020***	0.007	-0.027
	(0.00001)	(0.006)	(0.009)	(0.020)
2012	-0.00002	0.006	0.031***	0.057***
	(0.00002)	(0.006)	(0.009)	(0.021)
2017	0.00001	0.020***	0.017*	0.098***
	(0.00002)	(0.006)	(0.009)	(0.021)
% Housing Unit Interaction* Medium Density Rail				
1980	0.00007**	-0.011	0.057**	0.086
	(0.00003)	(0.011)	(0.028)	(0.060)
1990	0.00007***	-0.0331***	-0.021	0.094*
	(0.00003)	(0.010)	(0.024)	(0.053)
2012	0.00002	-0.001	0.007	0.114***
	(0.00003)	(0.009)	(0.020)	(0.044)
2017	0.00008**	0.012	0.008	0.132***
	(0.00003)	(0.009)	(0.020)	(0.043)
% Housing Unit Interaction* High Density Non-Rail				
1980	0.00008***	-0.008	0.072***	0.050*
	(0.00002)	(0.006)	(0.015)	(0.028)
1990	0.00009***	-0.04***	-0.001	-0.023
	(0.00002)	(0.006)	(0.014)	(0.028)
2012	0.00002	0.002	0.036***	0.104***
	(0.00002)	(0.006)	(0.014)	(0.032)
2017	-0.00003	0.025***	0.004	0.083***
	(0.00002)	(0.006)	(0.014)	(0.032)
% Housing Unit Interaction* High Density Rail				
1980	0.0002***	-0.023***	0.067**	-0.147***
	(0.00005)	(0.008)	(0.0310294	(0.056)
1990	0.0003***	-0.087***	-0.114***	0.062
	(0.00003)	(0.008)	(0.029)	(0.053)
2012	0.000009	-0.005	0.045*	0.016
	(0.00004)	(0.007)	(0.023)	(0.048)
2017	-0.00001	0.032***	0.026	-0.050
	(0.00004)	(0.007)	(0.023)	(0.047)
Constant	5.368***	5.480***	5.575***	5.321***
	(0.526)	(0.328)	(0.300)	(0.319)
Observations	110,700	110,700	110,700	110,700
Number of groups	27	27	27	27
Wald test	207929***	208155***	208119***	207950***
Linear Regression test	12331***	11984***	12160***	13022***

*** p<0.01, ** p<0.05, * p<0.1

Table VII-4: Welch Analysis of Variance (ANOVA) of Estimated Average Household Transportation Costs by Neighborhood Type

Neighborhood Type	Auto-oriented	Transit-adjacent	Non-rail intermediate	Rail-oriented intermediate	Non-rail pedestrian-friendly
	Difference	Difference	Difference	Difference	Difference
Transit-adjacent	1194.464***				
Non-rail intermediate	2310.147***	1115.683***			
Rail-oriented intermediate	5435.639***	4241.175***	3125.492***		
Non-rail pedestrian-friendly	3929.092***	2734.628***	1618.945***	-1506.547***	
Transit-oriented	6699.923***	5505.459***	4389.776***	1264.284***	2770.831***

*** p<0.01, ** p<0.05, * p<0.1

Table VII-5: Neighborhood Housing Supply Model on Housing Affordability

	Housing Cost Burden		Neighborhood Affordable at 80% Area Median Income	
	% Non-Rail Pedestrian-Friendly Units Interaction	% Rail-Oriented Intermediate Units Interaction	% Non-Rail Pedestrian-Friendly Units Interaction	% Rail-Oriented Intermediate Units Interaction
VARIABLES	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)	Coef. (Std Err)
Block-group Level				
% Black	-0.020***	-0.019***	-0.014***	-0.017***
	(0.001)	(0.001)	(0.0008)	(0.0008)
% Hispanic	-0.038***	-0.038***	-0.014***	-0.016***
	(0.002)	(0.002)	(0.001)	(0.001)
% Age 25-39	0.051***	0.053***	0.019***	0.019***
	(0.003)	(0.003)	(0.002)	(0.002)
Average Household Size	0.015	-0.011572	-0.029	0.077***
	(0.052)	(0.052)	(0.033)	(0.028)
% Small Housing Units	-0.057***	-0.057***	-0.043***	-0.022***
	(0.002)	(0.002)	(0.001)	(0.001)
% New Development	0.036***	0.036***	0.015***	0.014***
	(0.002)	(0.002)	(0.001)	(0.001)
Median Household Income (1000s)	0.120***	0.121***	0.051***	0.036***
	(0.001)	(0.001)	(0.001)	(0.001)
Neighborhood Type (Reference: Auto-oriented)				
Transit-adjacent	0.280	-1.178***	-0.11461	-0.47407***
	(0.290)	(0.228)	(0.17700)	(0.13815)
Non-rail intermediate	0.268**	-0.127	-0.46371***	-0.15289***
	(0.118)	(0.083)	(0.07948)	(0.04925)
Rail-oriented intermediate	0.527**	-0.605***	-0.42768**	-0.54140***

	(0.230)	(0.184)	(0.16992)	(0.12517)
Non-rail pedestrian-friendly	0.751***	-0.270*	-0.36816**	-0.13820*
	(0.208)	(0.139)	(0.14615)	(0.08007)
Transit-oriented	1.188***	-0.129	0.11698	0.29028*
	(0.306)	(0.252)	(0.21950)	(0.15211)
Distance to Highway Ramp	-0.042***	-0.046***	-0.02905***	-0.01592*
(Km)	(0.015)	(0.015)	(0.00889)	(0.00839)
Distance to Rail (Km)	-0.015***	-0.018***	-0.00903***	0.00267
	(0.003)	(0.003)	(0.00222)	(0.00221)
Distance to CBD (Km)	0.006***	0.006***	0.01197***	0.00038
	(0.002)	(0.002)	(0.00134)	(0.00098)
Job Accessibility	0.001***	0.001***	-0.00041***	0.00025***
	(0.00007)	(0.00007)	(0.00004)	(0.00004)
% Housing Units				
(Reference: Auto-oriented)	0.008	-0.521**	-0.08050	-0.16808**
	(0.183)	(0.207)	(0.10438)	(0.07183)
Transit-adjacent	-0.141***	0.049**	-0.01944	0.02596**
	(0.034)	(0.01958)	(0.02018)	(0.01025)
Non-rail intermediate	-0.053***	-0.00105	0.00750	0.01414***
	(0.012)	(0.00797)	(0.00814)	(0.00399)
Rail-oriented intermediate	-0.097***	0.03685***	-0.04745**	0.04183***
	(0.027)	(0.01182)	(0.02066)	(0.00669)
Non-rail pedestrian-friendly	-0.079***	0.03786***	-0.02801**	0.02112***
	(0.018)	(0.01164)	(0.01302)	(0.00559)
Transit-oriented	-0.05890*	0.06592***	-0.08032***	0.01046
	(0.03163)	(0.01513)	(0.02587)	(0.00797)
Population (1000s)	0.0007***	0.00109***	0.00035***	0.00038***
	(0.0002)	(0.00026)	(0.00012)	(0.00009)
Median House Value		0.00026		0.00102
(1000s)		(0.00593)		(0.00206)
Constant	10.152***	10.76459***	-3.85996***	-5.20952***
	(1.627)	(1.81085)	(0.93107)	(0.63670)
Observations	52,573	52,573	52,573	52,573
Number of groups	23	23	23	23
Wald test	50406***	50393***	9871***	8942***
Linear Regression test	22022***	16182***	18396***	7564***

*** p<0.01, ** p<0.05, * p<0.1

Table VII-6: Transportation Affordability Models

VARIABLES	Housing Cost Burden CBD Model Coef. (Std Err)	 Rail Model Coef. (Std Err)	Neighborhood Affordable at 80% Area Median Income CBD Model Coef. (Std Err)	 Rail Model Coef. (Std Err)
Block-group Level				
% Black	-0.01218***	-0.01531***	-0.01339***	-0.01549***
	(0.00031)	(0.00031)	(0.00092)	(0.00092)
% Hispanic	-0.01172***	-0.01531***	-0.00595***	-0.00760***
	(0.00039)	(0.00040)	(0.00132)	(0.00130)
% Age 25-39	-0.02528***	-0.02593***	-0.06614***	-0.06342***
	(0.00071)	(0.00073)	(0.00247)	(0.00244)
Average Household Size	0.16648***	0.17988***	0.01437	0.05786
	(0.01278)	(0.01311)	(0.04565)	(0.04467)
% Multi-family Housing Units	-0.03547***	-0.03517***	-0.04302***	-0.04074***
	(0.00029)	(0.00030)	(0.00104)	(0.00101)
Median Household Income (1000s)	0.02975***	0.02799***	0.05274***	0.04913***
	(0.00021)	(0.00021)	(0.00109)	(0.00108)
Neighborhood Type (Reference: Auto-oriented)				
Transit-adjacent	-0.23436***	-0.26196***	-0.25507**	-0.05969
	(0.03753)	(0.03879)	(0.11450)	(0.11460)
Non-rail intermediate	-0.82569***	-1.01856***	-1.25713***	-1.39044***
	(0.01654)	(0.01669)	(0.05676)	(0.05579)
Rail-oriented intermediate	-1.03087***	-1.15509***	-1.65066***	-1.51724***
	(0.02969)	(0.03052)	(0.08594)	(0.08602)
Non-rail pedestrian-friendly	-1.42646***	-1.75002***	-1.95957***	-2.14393***
	(0.02817)	(0.02837)	(0.08253)	(0.08161)
Transit-oriented	-1.35113***	-1.52762***	-2.23734***	-2.14607***
	(0.03962)	(0.04060)	(0.12465)	(0.12414)
Distance to Highway Ramp (Km)	0.03882***	0.06965***	0.11926***	0.12162***
	(0.00359)	(0.00372)	(0.01950)	(0.01851)
Distance to Rail (Km)	0.02612***		0.06153***	
	(0.00042)		(0.00233)	
Distance to CBD (Km)		0.01773***		0.07339***
		(0.00082)		(0.00509)
Job Accessibility	-0.00306***	-0.00341***	-0.00413***	-0.00527***
	(0.00002)	(0.00002)	(0.00011)	(0.00010)
Metropolitan Level				
Housing Units per Acre	1.68538*	1.91761**	1.30027	1.46083
	(0.88280)	(0.88676)	(1.38921)	(1.29465)
Fixed-Guideway Vehicle Revenue Miles (Millions)	-0.00496	-0.00429	-0.01101	-0.00903
	(0.00544)	(0.00546)	(0.00855)	(0.00797)

Constant	10.49107***	10.53540***	0.85427	1.16811
	(2.31969)	(2.33016)	(3.65235)	(3.40399)
Observations	63,905	63,905	63,905	63,905
Number of groups	23	23	23	23
Wald test	342911***	322097***	6897***	7056***
Linear Regression test	71592***	69119***	19861***	18430***

*** p<0.01, ** p<0.05, * p<0.1

Table VII-7: Location Affordability Models

	Housing Cost Burden			Neighborhood Affordable at 80% Area Median Income	
VARIABLES	Neighborhood Type Coef. (Std Err)	CBD Model Coef. (Std Err)	Rail Model Coef. (Std Err)	CBD Model Coef. (Std Err)	Rail Model Coef. (Std Err)
Block-group Level					
% Black	-0.0367***	-0.02868***	-0.03287***	-0.01410***	-0.01545***
	(0.0012)	(0.00126)	(0.00124)	(0.00084)	(0.00083)
% Hispanic	-0.0496***	-0.04077***	-0.04489***	-0.01374***	-0.01477***
	(0.0016)	(0.00159)	(0.00158)	(0.00097)	(0.00096)
% Age 25-39	0.0203***	0.03419***	0.03270***	0.01939***	0.01885***
	(0.0030)	(0.00295)	(0.00296)	(0.00185)	(0.00185)
Average Household Size	-0.0987*	-0.13154**	-0.12305**	-0.02091	-0.01921
	(0.0549)	(0.05448)	(0.05461)	(0.03266)	(0.03264)
% Small Housing Units	-0.1100***	-0.10337***	-0.10366***	-0.04253***	-0.04244***
	(0.0015)	(0.00151)	(0.00152)	(0.00103)	(0.00103)
% New Development	0.0392***	0.03471***	0.03696***	0.01484***	0.01557***
	(0.0018)	(0.00177)	(0.00177)	(0.00108)	(0.00108)
Median Household Income (1000s)	0.1400***	0.14659***	0.14423***	0.05110***	0.05021***
	(0.0011)	(0.00106)	(0.00105)	(0.00083)	(0.00082)
Neighborhood Type (Reference: Auto-oriented)					
Transit-adjacent	-0.9899***	-0.63566***	-0.76135***	-0.21623**	-0.26070***
	(0.1559)	(0.15461)	(0.15614)	(0.09469)	(0.09493)
Non-rail intermediate	-1.1514***	-0.68535***	-0.93712***	-0.39328***	-0.48008***
	(0.0660)	(0.06761)	(0.06659)	(0.04470)	(0.04377)
Rail-oriented intermediate	-2.8557***	-1.00125***	-1.20795***	-0.78180***	-0.85444***
	(0.1051)	(0.11548)	(0.11595)	(0.07145)	(0.07131)
Non-rail pedestrian-friendly	-1.8371***	-0.97701***	-1.38144***	-0.66389***	-0.79843***
	(0.1060)	(0.10867)	(0.10655)	(0.06811)	(0.06637)
Transit-oriented	-2.7349***	-0.44077***	-0.70868***	-0.51077***	-0.59967***
	(0.1386)	(0.15032)	(0.15039)	(0.08911)	(0.08869)
Distance to Highway Ramp (Km)	0.0398***	-0.03079**	0.01812	-0.03447***	-0.01713*
	(0.0147)	(0.01497)	(0.01508)	(0.00880)	(0.00876)
Distance to CBD (Km)		0.02820***		0.00917***	

		(0.00171)		(0.00114)	
Distance to Rail (Km)			0.00494		0.00087
			(0.00323)		(0.00191)
Job Accessibility (1000s)		-0.00182***	-0.00218***	-0.00043***	-0.00053***
		(0.00007)	(0.00006)	(0.00004)	(0.00004)
Metropolitan Level					
Median House Value (1000s)	0.0003	-0.00042	0.00018	0.00012	0.00031
	(0.0118)	(0.01157)	(0.01176)	(0.00434)	(0.00437)
Fixed-Guideway Vehicle Revenue Miles (Millions)	0.0105	0.01125	0.01231	0.00510	0.00540
	(0.0146)	(0.01432)	(0.01456)	(0.00537)	(0.00540)
Constant	30.8049***	29.30087***	30.02957***	-3.13625**	-2.90125**
	(3.5803)	(3.51080)	(3.56884)	(1.32046)	(1.32919)
Observations	52,818	52,573	52,573	52,573	52,573
Number of groups	23	23	23	23	23
Wald test	90857***	94375***	93628***	9856***	9871***
Linear Regression test	49894***	48061***	50516***	23426***	24545***

*** p<0.01, ** p<0.05, * p<0.1

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