Transit-Induced Gentrification in U.S. Metropolitan Areas

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ABSTRACT

Problem: Gentrification is a term used to describe the process and changes that commonly occur in lower-income and/or minority neighborhoods with the influx of more affluent residents who are more likely to be white, increases in property values, the renovation of housing, the upscaling of local commercial and retail properties, and potentially, the displacement of current residents. Some studies in the past two decades have found that the sustained growth of the high-quality public transit systems—both rails and buses—may have triggered or accelerated gentrification in some U.S. metropolitan areas (MSAs). Some studies define that phenomenon as the "Transit-Induced Gentrification" (TIG). Until now, nineteen empirical studies have examined TIG in one or several cities, with twelve of them focused on American cities. Some fundamental studies have been conducted to explain TIG based on previous theories and hypotheses of the traditional gentrification. Through the summary of literature, three unsolved issues on TIG have been identified. First, current studies have not reached consensus on the pervasiveness of TIG, partly because of their different operational definitions and measures of gentrification and their different research designs. Second, current studies have not found sufficient empirical evidence to support the hypotheses explaining TIG, and factors associated with the probability of TIG are not clear. Third, scholars are still not clear about whether displacement always happens during the TIG.

Research strategy and findings: This dissertation is designed to address the first two unresolved issues. With a quasi-experimental design, this dissertation examines the hypothesis of TIG in all neighborhoods newly served by rapid transit stations that opened from 2000 through 2009 across the U.S. This dissertation confirms that TIG is likely but not inevitable by comparing the pretest-posttest results between all new rapid-transit-served neighborhoods and a control group selected by nonparametric propensity score matching that controls for neighborhood characteristics and the impact of *Great Recession*. This dissertation provides the first comparison of the likelihood of gentrification associated with both rail and bus rapid transit (BRT) and shows that rail stations are more likely to induce gentrification than BRT stops. This dissertation also shows that TIG is more evident over long-term than over short-term for rail-served neighborhoods. Methodologically, although some previous studies have used Census block groups (CBGs) as the areal unit of analysis, most have used Census Tracts (CTs), and none has compared results from simultaneous analysis using both CBGs and CTs. This dissertation makes a contribution by comparing results from using both CBGs and CTs as the areal unit of analysis. The comparisons show that CBG-based analyses better approximate the areas served by transit stations, are more consistent with

theory, and therefore provide more valid results. This dissertation also applies the multi-level (hierarchical) logistic regressions to identify and examine factors that are likely to be associated with the probability of TIG, including both MSA and neighborhood characteristics. The results show that MSA characteristics are less stable and provide less and evidence of the probability of TIG than neighborhood characteristics. Some socioeconomic characteristics of neighborhoods, mainly measures of poverty, show consistent significance in the examinations for their impact on the likelihood of TIG.

Take Away for Practice: The findings of this study have some policy implications. The BRT is less likely to induce gentrification compared with rail transit, and thus could help sustain the transit service to the most vulnerable without the same likelihood of gentrification. The identification of neighborhoods with higher probability of TIG, such as the neighborhoods with higher poverty rates and people of color and lower proportions of college-educated residents, enables policy-makers and urban planners to target policies such as affordable housing and rent ceilings to assist the most vulnerable areas and residents. In addition, the use of different definitions and measurements of TIG results in substantial differences in the percentages of neighborhoods classified as experiencing gentrification and in identification of different factors that affect the probability of TIG. These findings can be interpreted as evidence that policy makers and planners need to involve stakeholders, especially the low-income and people of color who are more vulnerable to gentrification, in their deliberations over definitions of TIG and when establishing anti-gentrification policies.

Contents

List of Figures

List of Tables

Chapter 1: Introduction

Gentrification is a term used to describe the process and changes that commonly occur in lower-income and/or minority neighborhoods with the influx of more affluent residents who are more likely to be white. Frequently observed changes include increases in property values, the renovation of housing, the upscaling of local commercial and retail properties, and potentially, the displacement of current residents. Gentrification first was used to describe the phenomenon of the invasion of the working class in the urban core by the middle class in large cities like London (Glass, 1964). The meaning of gentrification was expanded during the following decades to include the process of succeeding waves of different types of newcomers and the invasion of the different classes of inhabitants in the urban core. Therefore, the conceptualization of gentrification were changed. For example, the working class has been redefined as the low-income and/or minorities, and the middle class has been redefined as the more affluent residents. Since 2000, some new features of gentrification have shown. For example, the gentrification in the urban core of large cities has escalated; it also has expanded to the neighborhoods far from the urban core and to neighborhoods in smaller cities. The escalation and expansion of gentrification have raised concerns to the public due to the "primary harms" associated with gentrification, such as exclusion; transformation of public, social, and commercial space; polarization; homogenization; and residential displacement (Kohn, 2013).

These new features of gentrification are hypothesized to be associated with the changes in industrial structure, social value and preferences, as well as the some public investment oriented to enhance the level of public service (Hwang & Lin, 2016; Zuk et al., 2018). Among multiple types of public investment, public transit, with its rapid development during the past two decades, is one of the major suspected triggers of the new round of gentrification. Gentrification has become one of the major concerns in the deliberation of transit planning, especially the planning of the high-quality transit.

The term high-quality public transit usually refers to transit with frequent, stable, fast service and good connectivity (Glascock, 1997), such as rail transit and some Bus Rapid Transit (BRT) systems, especially the systems viewed as high-end BRT. The capital funding of transit systems grew from $5.1 billion in 1991, to $9.1 billion in 2000, and $19.5 billion in 2015, with an annual growth rate as 5.8% between 1991 and 2015 (Federal Transit Administration, 2018). Among all transit modes, the high-quality transit systems remained appealing, attracting the most public investment. For example, in 2015, the total capital funding for rail transit, including heavy rail, light rail, and commuter rail, was $13.5 billion, accounting for 68.4% of the total capital funding on public transit. From 1995 through 2015, 17 additional commuter/hybrid rail systems and 13 additional light rail/streetcar systems were constructed. In addition, twelve BRT systems were operating in 2015, which was double the number in 2010 (American Public Transportation Association, 2017).

These higher-quality transit systems have contributed substantially to transit ridership. From 1991 through 2015, the overall public transit ridership (Unlinked Passenger Trips, UPT) grew from 8.5 billion to 10.6 billion, with a growth rate of 25.3%, whereas the ridership of the rail transit grew from 2.7 billion to 5.0 billion, with a growth rate of 85.3% (American Public Transportation Association, 2020). Among these rail transit modes, the light rail transit (LRT) had the greatest increase in ridership, with a 209% increase in the UPT. In addition, during the 15 years (1991 – 2015), the proportion of ridership of the rail transit among the overall transit use increased from 31.6% to 46.7% (American Public Transportation Association, 2020). The UPT of the BRT was 54.9 million in 2015, whereas there was only 16.0 million in 2012, at the year when the American Public Transportation Association started to collect BRT data.

The large investments in high-quality transit are usually oriented to reducing auto use, providing mobility, attracting investment, and supporting local economy (Chatman et al., 2019; Tehrani et al., 2019). The increased ridership of has achieved some of those targets such as reducing auto use and providing mobility. However, these high-quality transit systems are also critiqued for targeting suburban commuters rather than the low-income in the inner city, most of whom are transit-dependents (Grengs, 2010), and for raising the concern of gentrification and the pressure of displacement in neighborhoods along the transit corridors (Tehrani et al., 2019). The planning of the high-quality transit sometimes receives objections from the local community due to the concerns of gentrification (e.g. Lindblom, Nov. 15, 2019). Therefore, transit planners and policy makers are seeking to understand the relationship between these high-quality transit lines and gentrification.

The phenomenon that the transit could trigger or accelerate gentrification is defined as "Transit-Induced Gentrification" (TIG). Scholars, however, have not reached a consensus on the likelihood and pervasiveness of TIG. To date, 19 empirical studies have examined TIG in one or several cities, with 12 of them focused on American cities. These empirical studies usually have used different operational definitions and corresponding measures of gentrification, and these definitions and measures are not consistent. Most of these studies use descriptive statistics or regression models to examine the before-and-after changes in the transit-served neighborhoods or the distance-decay of indicators of gentrification around the transit stations. Evidence from qualitative studies has also verified the gentrification pressure such as rent appreciation, and residential displacement. Both cross-sectional and cohort-based evidence have demonstrated the significance of TIG in some cities, but some studies also have found little evidence of TIG in other cities. Apart from these empirical studies, studies have also developed theories to explain TIG based on the traditional neoclassical economic and Marxism frameworks of gentrification. Other studies have proposed hypothesis to explain TIG, saying that TIG is the endogenous outcome of Transit-Oriented Development (TOD). The neoclassical economic framework of gentrification is applied more in the empirical studies explicitly or implicitly than the Marxism framework. However, none of the empirical studies has examined the intermediate mechanisms of how transit triggers or accelerates gentrification, such as the commuting mode or consumption preference changes, or the decision-making process of the developers.

Through the summary of current studies on TIG, three literature gaps have been identified. 1) Current examinations of TIG indicate that TIG has occurred in some but not all cities and that the pervasiveness of TIG varies in cities where it has been documented. However, no nation-wide examinations have been conducted to verify the occurrence and scale of TIG with a consistent operational definition and measure of gentrification. 2) Few empirical studies have tested the fundamental hypotheses of TIG, as well as the associated factors that could affect the probability of TIG. 3) Scholars have not reached consensus on the relationship between TIG and displacement, specifically, whether displacement always happens during TIG.

In addition, many previous studies of TIG have methodological limitations. First, most previous studies use Census tracts (CTs) as the areal unit of analysis. CTs usually are larger than the service areas of the transit stations. Detecting the changes in the larger CTs to examine the TIG could sometimes confound the results. Therefore, smaller areal unit of analysis are needed in the TIG studies to isolate the impact of the transit stations. Second, some studies define the service areas of transit stations as the contiguous units or circular buffers around stations, without considering the road networks (i.e., the actual walking route from/to the station). This limitation could distort the results as well. Therefore, a more valid definition of the service areas of transit stations is needed.

Building on these studies, this dissertation is designed to contribute to two of the literature gaps by answering two major research questions: *1) Do rapid transit lines induce gentrification in U.S. metropolitan areas (MSAs)?*, and *2) What factors affect the occurrence of transit-induced gentrification in U.S. MSAs?* This dissertation does not analyze the problem of displacement. Figure 1 summarizes the overall research design and illustrates the linkages between the two primary research questions.

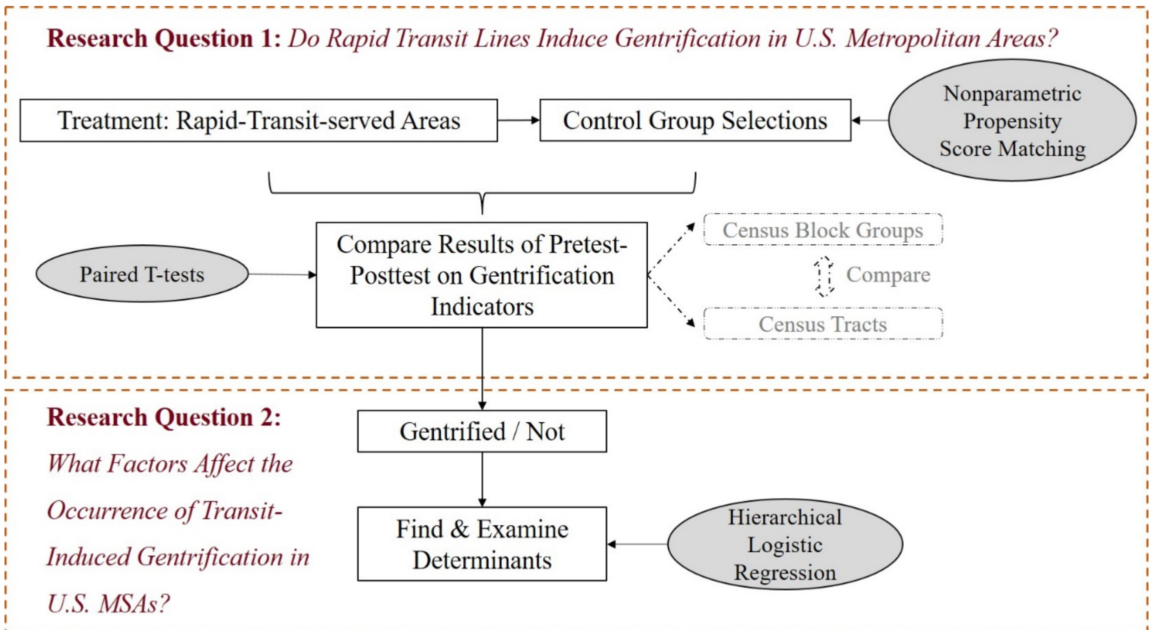

Figure 1 The Design of This Dissertation

To answer the first question, a pretest-posttest quasi-experimental design is applied to examine whether the gentrification occurred in all areas served by new rapid transit stations that opened between 2000 and 2009 in the U.S. (Figure 1). The indicators of gentrification for these new transit-served areas are compared to the same indicators for the corresponding control areas selected by nonparametric propensity score matching. This methodology controls for sociodemographic, housing, and location characteristics, as well as the impact of the *Great Recession*. Through the comparison, the results show rail stations are more likely to induce gentrification than bus rapid transit (BRT) stops.

To answer the second question, the multi-level (hierarchical) logistic regression is used to identify and examine factors that are likely to be associated with the occurrence of TIG (Figure 1). These factors include physical, infrastructural, and socioeconomic characteristics at metropolitan-level as well as physical and socioeconomic factors at census-block-group (CBG) or neighborhood level. The analysis shows the MSA-level characteristics have weaker and less stable association with the probability of TIG than CBG characteristics. Some socioeconomic characteristics of CBGs, mainly measures of poverty, show consistent significance in the examinations for their impact on the likelihood of the occurrence of TIG. The examinations controlling for physical and socioeconomic factors find evidence of the higher probability of TIG in rail-served CBGs than BRT-served CBGs, but the evidence is not consistent and stable. Measures of capital accumulation, suggested by Marxism framework, do not show significant impact on the likelihood of the occurrence of TIG. The location of the CBG and overall transit service level of the MSA, suggested by neoclassical economic framework, do not show consistent and stable impact on the likelihood of the occurrence of TIG. Therefore, little evidence has been found to support either of the two theories explaining TIG in this study.

In addition to answering the two important questions to fulfil the literature gaps, this dissertation also addresses the limitations of methodologies in previous studies. To better match the areas served by transit stations, CBGs are used as the principal areal unit of analysis and then compare with CTs. To complete these analyses, a longitudinal (1990 – 2014) nation-wide socioeconomic dataset was created at both Census block group and Census tract levels. Creation of the dataset required use of interpolation methods for block-level data using *GIS*, *Stata* and *R* jointly. The network-based analysis in *GIS* was used to generate and select service areas of transit stations, which are defined as the areas accessible within a half-mile walking distance from the transit stations. Within the same research design, use of CBGs to assess changes in TIG indicators yields different results than analyses using Census tracts. This comparison thus confirms the potential risk of bias due to different definitions of transit-served neighborhoods, and suggests that CBGs could be a better choice than Census tracts with regard to the service area of the rapid transit stations.

In this dissertation, Chapter 2 is a review of the literature on TIG that draws, where relevant, on the broader literature on gentrification. Chapter 3 is designed to answer the first research question about whether the newly opened rapid transit stations induce gentrification in the neighborhoods they serve, and Chapter 4 identifies and examines the factors that affect the probability of TIG. Finally, Chapter 5 summarizes major discussions and conclusions of this dissertation.

Chapter 2: Transit-Induced Gentrification: A Review of Evidence

2.1 Introduction: Transit Development and Potential Gentrification

Gentrification is a term used to describe the process and changes that commonly occur in lower-income and/or minority neighborhoods with the influx of more affluent residents, who are disproportionately White. These changes generally include increases in property values and rents; the renovation of housing and amenities; the upscaling of local commercial and retail properties; and potentially, the displacement of current residents. Scholars have discovered that gentrification in U.S. cities has accelerated and shown new features since the 2000s (Hwang & Lin, 2017). The increasing public investment in public transit is hypothesized to be one of the triggers of recent, higher rates of gentrification (Revington, 2015; Zuk et al., 2015; Zuk et al., 2017; Tehrani et al., 2019; Padeiro et al., 2019). Some scholars use the "Transit-Induced Gentrification" (TIG) to describe the phenomenon that gentrification occurs due to the growth of transit-accessibility in gentrifiable transit-served neighborhoods.

The phenomenon of TIG emerges after the 2000s in both transit-dominant cities and auto-dominant cities with the rapid development of public transit systems, usually associated with the Transit-Oriented Development (TOD) policies (Tehrani, Wu, & Roberts, 2019; Padeiro, Louro, & Costa, 2019). For example, Beijing, capital of China, has experienced significant gentrification around the newly opened subway stations, following the rapid extension of subway lines after winning the bid to host 2008 Summer Olympic Games (Zheng & Kahn, 2013). The gentrification in Beijing is measured as the increases of housing prices and proportions of residents with higher income or higher-income potential in the subway-served neighborhoods compared to other neighborhoods nearby. It is easy to understand the presence of TIG in the transit-dominant cities like Beijing, due to the extensive public transit systems and their higher usage rates. For example, usually half of all commuting trips or above[1] are made by transit in those transit-dominant cities (Qi & Sun, 2020).

In contrast, auto-dominant cities such as most mid-size U.S. cities are usually presumed to be more resistant to TIG, and the impact of rapid transit development is more complex than the impact in transit-dominant cities. Scholars have documented premiums of sales prices of homes and "rent hikes" along the high-quality transit corridors (e.g. Nelson, 1992; Landis et al., 1995;

[1] In 2015, transit shares a proportion of 50% in the overall commuting trips, whereas private vehicles shares 31.9% (Beijing Transportation Development Report, 2016).

Henneberry, 1998; Cevero & Duncan, 2002; Debrezion et al., 2007; Hess & Almeida, 2007; Dziauddin & Alvanides, 2015; Chatman et al., 2019). These higher housing costs sometimes occur together with intensive development such as newly built homes, upgrading of amenities, and upscaling of local commercial or retail properties near transit stations or along routes. In addition, some sociodemographic changes are also found, such as higher population density or in-migration of wealthier households that has potential to displace the previous residents (Chatman et al., 2019; Tehrani et al., 2019). These integrated changes are the typical characteristics of gentrification. The scholars have also argued, however, that wealthier people could be discouraged from moving into the transit-served neighborhoods due to congestion or related conditions, shortages of large and comfortable apartments, poor parking availabilities, and safety concerns such as high crime rates (Padeiro et al., 2019). Some studies have documented little evidence of gentrification in some rapid-transit-served areas. For example, both Dong (2017) and Baker & Lee (2017) have not found any evidence of TIG in the neighborhoods along the rail transit lines in Portland.

The complexity of the impact of transit opening on its surrounding neighborhoods could have added concerns and lengthened the deliberation of transit planning. Usually, most public transit projects and their route designs carry the tasks of mobility/transportation justice, to be more specific, providing better accessibility for transit-dependents (Grengs, 2005; Sandoval, 2018). The gentrification that could happen in the neighborhoods along the transit corridors, however, could be at odds with the objectives of mobility/transportation justice due to the potential adverse consequences that are usually associated with gentrification, such as the displacement of the original low-income residents prior to the transit system opened (Revington, 2015; Smith, 1979; Padeiro et al., 2019). Therefore, planners and policy makers have evidence of TIG for the transit planning, especially for the planning of rapid transit.

The majority of studies on the rapid transit development have focused on the Transit-Oriented Development (TOD) policies, which are intended to reduce the auto use for congestion concerns or carbon emissions through raising transit ridership (Chatman et al., 2019), to attract the investment of developers in new condominiums/housing or the upscaling of the old ones (Tehrani et al., 2019), as well as to enhance local economic development and establish a “sense of place” at transportation nodes (or place-making in the neighborhoods contiguous to the transit nodes) (Hess & Lombardi, 2004; Dorsey & Mulder, 2013). Studies of TOD have usually focused on the impact of transit on “building environment spectrum” such as economic clustering and sometimes housing for neighborhoods TODs (Hess & Lombardi, 2004; Tehrani et al., 2019). Some of these studies also have noticed the changes of social environment, such as the move-in of households with higher income or income potential, which are usually the characteristics of gentrification, in areas contiguous to transit systems (e.g. Rayle, 2015), but most TOD studies have not clearly focused on or measured gentrification (e.g. Duncan, 2011). As a result, most studies of TOD provide little evidence on the occurrence and magnitude of TIG.

Excluding these studies of TOD, only 19 empirical studies of TIG have been reported, with only 12 of these studies focused on U.S. cities or metropolitan areas. These studies offer useful evidence and insights into the pervasiveness of gentrification. This chapter is designed to review the pioneering works of TIG, based on the review of definitions and fundamental studies of gentrification.

2.2 Definitions of Gentrification

The term "gentrification" was first explicitly used to describe a "new urban gentry" and the phenomenon that the "working-class quarters of London had been invaded by the middle classes—upper and lower" during the 1950s and 1960s (Glass, 1964). During decades since 1964, the term "gentrification" was used without a clear consistent definition of the characteristics that establish the occurrence of gentrification (Ellen & O'Regan, 2012). For example, the socioeconomic and sociodemographic characteristics of neighborhoods to define and measure gentrification are different across the studies on gentrification. In addition, scholars have divergent opinions in the role of residential displacement when defining gentrification. Some studies have viewed the residential displacement caused by the neighborhood change during gentrification as one of the essential element in gentrification definitions (e.g., Kennedy & Leonard, 2001; Sanchez et al., 2003; Rayle, 2015; Tehrani et al., 2019); whereas some other studies have viewed the displacement as a concern but not a necessary consequence of gentrification (e.g., Newman & Wyly, 2006; Ding et al., 2016; Padeiro et al., 2019).

Even though the characteristics that ascertain/establish the occurrence of gentrification are not unified in the literature, scholars have agreed that the basic characteristic of gentrification is the higher overall socioeconomic status of the residents in the gentrified/gentrifying neighborhoods and that all definitions should include measures of this characteristics (Hwang & Lin, 2017). Residentially, this basic characteristic of gentrification could appear as the influx of more affluent residents (i.e., the gentrifiers) such as the middle-class workers based on Glass's definition.

Scholars have specified the more affluent residents to include the "cultural new class" (including artists, designers, and media workers), the young professionals or pre-professionals (such as students) with higher-income potential, the educators, social and health care workers, as well as the professional, technical, and managerial workers with higher education and higher income (Marcus, 1986; Ley, 1996; Danyluk & Ley, 2007; Ellen & O'Regan, 2012; Dong, 2017; Zuk et al., 2017). These more affluent residents are usually disproportionate (Zuk et al., 2017). In addition to the residential characteristics, the higher overall socioeconomic status of the gentrifying/gentrified neighborhoods also appears as the changes of other characteristics. These other characteristics can be summarized into three categories: 1) the improvement in housing characteristics, such as property value, rent, housing density, and amenities, which are usually associated with capital investment (e.g., Lin, 2002; Kahn, 2007; Feinstein & Allen, 2011); 2) the upgrading of economic activities, mostly local commercial establishments such as the retail stores and restaurants in the neighborhoods (Hwang & Lin, 2017; Zheng & Kahn, 2013; Zuk et al., 2015); and 3) the changes in transportation-related activities, such as the public transit ridership and vehicle ownership (Pollack et al., 2010; Brown, 2016).

Previous studies define gentrification based on one subset of the gentrification characteristics listed above, if not viewing displacement as a necessary element of gentrification, and the choices of subset show high diversity. In these studies, the measures of gentrification follow their corresponding operational definitions. Therefore, each measure of gentrification is also the subset of indicators chosen from indicators of the demographic (i.e., residential), housing, economic, and transportation changes, and these measures are highly diversified as well. The diversity of definitions and measures of gentrification might lead to different conclusions in the examinations of gentrification for the same study subject (i.e., the same neighborhoods/regions during a specific period).

In addition, scholars' divergent opinions of the role of displacement could also increase the likelihood of different conclusions when examining gentrification of the same place. In the studies defining displacement as the essential element of gentrification, the occurrence of displacement is necessary for defining the occurrence of gentrification, and the measure of gentrification with diagnosing displacement is complicated. In addition to the working class in traditional definitions of gentrification, the displaced could also include other categories of residents such as the low-income, the low educated, the poor, the elderly, and the minority and ethnic group members (Marcus, 1986; Ellen & O'Regan, 2012; Dong, 2017). These scholars, who insisted that any gentrification definitions should include displacement, argued that the failure in observing displacement in gentrified/gentrifying neighborhoods could result from the anti-displacement policies (Rayle, 2015). They suggested that those anti-displacement policies would make the displacement have "slower, more diffuse, less visible and more ambiguous forms" (Rayle, 2015; Wyly et al., 2010). Moreover, some studies have distinguished two stages of displacement during the process of gentrification—the disinvestment displacement creates "vacant land ripe" for gentrification, and reinvestment displacement could then take place through the gentrification (Grier & Grier, 1978; Marcuse, 1985, 1986; Zuk et al., 2017). Due to the complexity of displacement associated with gentrification, those studies viewing gentrification as an essential element of gentrification have limited success in diagnosing displacement when measuring gentrification.

In contrast, in the studies viewing displacement as a concern but not a necessary consequence, a higher socioeconomic status of the residents is enough for defining the occurrence of gentrification in a neighborhood (Freeman & Braconi, 2004; Newman & Wyly, 2006; Rayle, 2015). The higher socioeconomic status is not necessarily caused by the displacement of the disadvantaged residents with lower socioeconomic status prior to the gentrification. Instead, it could be only driven by the largely in-movement of higher-income or affluent households, which only densified the neighborhood experiencing gentrification (Brurecker & Rosenthal, 2009; Kern, 1981; Kolko, 2007; Hwang & Lin, 2017). Alternatively, the gentrified/gentrifying neighborhoods with sufficient space for new housing and residents, such as the former industrial areas or depopulated residential areas, could be resistant to displacement as well (Rayle, 2015; Hamnet, 2009; Hamnett & Whitelegg, 2007). This means that socio-demographically, gentrification could produce social-mixing neighborhoods without crowding out the previous poor residents (Davidson, 2008; Baker & Lee, 2017). These scholars believed that the less substantial evidence of displacement in some empirical gentrification studies suggested that the upgrading of neighborhood could happen with minimal displacement (Butler, 2007; Freeman, 2011; Hamnett, 2009; Rayle, 2015).

Rayle (2015) attributes the dichotomy in the role of displacement among gentrification definitions to a few factors, including the effective anti-displacement policies (Ley & Dobson, 2008; Robinson, 1995; Walks & August, 2008), the various forms of gentrification (Hyra, 2008; Pattillo, 2008), or the different displacement pressures and forms during the successive phases of gentrification (Brown-Saracino, 2010; Lees et al., 2013; Zuk et al., 2017). These factors have added complexity when defining gentrification, and scholars' debate and divergent opinions in the role of displacement have added more risks of reaching to different conclusions when examining gentrification of the same study subject.

2.3 Theories and Hypotheses Explaining Gentrification and Its New Features

The theoretical perspectives on gentrification have evolved overtime. There are mainly two hypotheses and two theoretical frameworks to explain the gentrification, including the hypothesis of the change of residential segregation, the reinvasion-succession hypothesis, and two theoretical frameworks developed from the reinvasion-succession hypotheses: the bid-rent model raised by the neoclassical economists and the rent-gap theory raised by the Marxists. Since 2000, the emerging new features of gentrification have brought more hypotheses to explain the new features, such as the hypothesis explaining gentrification in the context of globalization, the hypothesis incorporating transportation into the traditional gentrification frameworks such as the Neoclassical economic framework and Marxian framework, and the new model to explain the natural lifecycle of housing.

The original fundamental explanation of gentrification during the 1950s to 1970s hypothesized that gentrification is a change of the historical patterns of residential segregation (Zuk et al., 2017). Driven by the changes of affluent workers' lifestyle and consumption habits, the re-centralization of professional service firms, and the urban renewal policies of governments, the first wave of in-movers moved back into the inner city, where there used to be concentration areas of the low-income or the working-class, who were disproportionate black (Smith, 1979; Zuk et al., 2017). The majority of these "pioneers" were the lower-middle class people with high education, such as the "cultural new class" (including artists, designers, and media workers), the young professionals or pre-professionals (such as students), and the educators, social and health care workers (Ley, 1996; Danyluk & Ley, 2007; Zuk et al., 2017). The first wave of "gentrifiers" enriched the diversity of the gentrifiable neighborhoods and revitalized the preference of living near the city centers (Lloyd, 2010; Danyluk & Ley, 2007). The enrichment of the diversity broke the previous residential segregation and the revitalization of the preference brought housing demand in the inner city. These changes stimulated the developers' re-investment on neighborhoods in the inner city, leading to another wave of gentrification. That second wave of gentrification was completed by the high-income and high-educated professionals, including lawyers, medical specialists, business people, and capitalists (Danyluk & Ley, 2007). In addition, those residential changes were associated with other changes in economic activities, amenities, and culture (Zuk et al., 2015). All those changes constituted the upgrading of the overall neighborhoods.

Scholars also have developed fundamental explanations of gentrification based on previous theories from the perspectives of sociologists and economists (Ellen & O'Regan, 2012). The invasion-succession model, as a theoretical construct in sociology, is initially introduced to explain the neighborhood change, which is the core change during gentrification (Ellen & O'Regan, 2012). Even though the invasion-succession model was originally used to explain neighborhood deterioration, some studies used the model reversely to explain the "reinvasion" of affluent groups into the gentrifiable neighborhoods, and the succession would occur until the original occupants of the neighborhood were completely displaced (Palen & London, 1984, Chap.1; Ellen & O'Regan, 2012). Based on the "reinvasion-succession" model, Palen & London (1984, Chap.1) summarized five hypotheses to explain the gentrification. 1) The hypothesis of demographic-ecological alternative indicates two types of reinvasion. First, the affluent, young, children-free couples tend to live in the city center, without worrying about the quality of inner-city schools and quantity of playground, and only worrying about the short commuting and close to adult recreation. The other type suggests that the cities whose sustenance organizations have more proportions of white-collar other than blue-collar activities are more likely to experience the reinvasion. 2) The hypothesis of sociocultural theoretical thrust suggests that the changing values, attitudes and lifestyles (Allen, 1977 chap. 2; Warner, 1962) or the dominant American values (Fusch, 1978; Williams, 1970) contribute to the reinvasion as the "urban pioneers". 3) The political-economic explanations include the traditional neoclassical explanation based on the competition, supply, demand, and market efficiency in the market and the Marxist framework based on the class power and uneven cost and benefit of the neighborhood change. These two frameworks are the major two frameworks cited most in the following gentrification studies. 4) The community network hypothesis suggests the characteristics of the community are significant in the process of neighborhood revitalization, such as the kinship, friendship, and ethnicity, as well as the local autonomy. 5) The fifth hypothesis emphasizes the impact of social movements, indicating the invasion to the city could be led by the role models of the new lifestyle seeker such as the first successful urban pioneers and political economic elites. The five reinvasion-based explanations of gentrification suggest that regional characteristics, such as the segmentalism, sustenance organizations, the stage of capital accumulation, extensiveness of public transit, social cultural changes, and diversity of the city, as well as the local characteristics like size, density, anonymity, and diversity of the neighborhood, would affect the pervasiveness of gentrification (Allen, 1984, chap. 2; Smith & Lefarvre, 1984 chap. 3).

Two theoretical frameworks, developed from the reinvasion-succession hypotheses, have been used specifically to explain gentrification. The first is the bid-rent model, which was raised by the neoclassical economists, suggesting that some interventions, such as the consumption preference changes, could alter the supply and demand balance in the housing or land market. From the demand perspective, the location advantage of housing in the inner city would win in the trade-off process when the cost of newly constructed housing in the suburban areas increases enough (Ellen & O'Regan, 2012; Palen & London, 1984; Brueckner, Thisse & Zenou, 1999; Helms, 2003). Whereas from the supply perspective, the end of the lifespan for the old houses in the inner city could initiate a new round of construction there, and the improved amenities attract more affluent residents and trigger the gentrification process (Brueckner & Rosenthal; 2009; Ellen & O'Regan, 2012). The other theoretical framework is the most widely used model to explain gentrification—the rent-gap theory based on the Marxism framework. Developers' reinvestment would start when the gap between the current capitalized ground rent and the potential ground rent becomes large enough to attract the capital investment (Smith, 1979; 1982). The rise of potential ground rent could be triggered by the cycle of capital accumulation (Harvey, 1973, 1978), and/or the urban renewal financial resources or investment commitments from non-market institutions (Edel, 1971), which might stimulate developers' re-investment on the construction or amenities of housing in the inner city.

These hypotheses and theoretical frameworks are used to explain the traditional gentrification phenomena. However, since 2000, some new features of gentrification have appeared. For example, the gentrification in the downtown areas has been escalated significantly (Hwang & Lin, 2017). Researchers have found that white, prime-age, college-educated households prefer the housing near downtown areas more since 2000 than before (Baum-Snow & Hartley, 2016; Couture and Handbury, 2016; Kolko, 2016). In addition, more remote neighborhoods beyond the immediate core have experienced gentrification, and the gentrification goes lower down the urban hierarchy to the smaller cities after the mega cities (Hackworth & Smith, 2001; Atkinston & Bridge, 2004 chap. 1), but those two trends vary among different metropolitan areas (Hwang & Lin, 2017). Scholars have summarized the factors that could play important roles in the recent gentrification, such as the accelerated return of high-skilled jobs to the downtown areas (Baum-Snow & Hartley, 2016), the long-lasting institutions (such as hospitals and universities) locating at the traditional downtown areas (Diamond, 2016), the scarcer leisure time among high-income households (Edlund, Machado, & Sviatschi, 2015), the concentration of commercial and public services, the improvement of amenities and public safety (Couture & Handbury, 2016; Kneebone & Garr, 2010; Ellen, Horn & Reed, 2017), and the government interventions such as high-quality transit systems (Hackworth & Smith, 2001; Revington, 2015; Zuk et al., 2015; Zuk et al., 2017). Moreover, the globalization process has also set a new context for gentrification (Hackworth & Smith, 2001; Atkinston & Bridge, 2004 chap. 1).

Some fundamental explanations have also been developed to explain these new features of gentrification since 2000, but these explanations have not been validly verified by empirical studies. For example, Atkinston and Bridge (2004 chap. 1) analyzed how globalization changed the traditional gentrification. First, they argued that the globalization not only brought the transnational corporations opening up in the city center, but also brought the transnational migrants. Second, the social networks of dialogue, and co-ordination among the professional and managerial groups, as well as the state and local governments emphasized the community agglomeration among like-minded people in the context of globalization. The social network, kin, friendship ties, and national background and heritage became the resources for job searching and co-ordination for both white- and blue-collar workers. The dense neighborhood-to-neighborhood geographical connections in the city center could create a good environment for those social network and co-ordination. Finally, the rent gap was expanded from locally to globally because of the globalization, and then led to the transnational investments in luxury residential developments, and even the involvement of architects with international reputations. However, few following studies have been conducted to verify these explanations of gentrification associated with globalization.

In addition, Revington (2015) introduced the role of transportation systems specifically into the two traditional gentrification theories. Based on the neoclassical framework, the transportation accessibility could be capitalized as higher land value and/or denser land use, and then induce gentrification, whereas based on the Marxist framework, the transportation development could be a trigger of the gentrification in the "gentrifiable" neighborhoods by enlarging the rent gap between potential ground rent and current capitalized ground rent. Current empirical examinations on whether transit could induce/trigger gentrification have involved these two hypotheses explicitly or implicitly. However, these examinations are limited to the occurrence of gentrification near transit, and few of them have examined the validity of the two hypotheses developed by Revington (2015) explaining why transit can induce/trigger gentrification.

Lee & Lin (2017) introduced a model based on the model of Tiebout (1956), which examined the geographic sorting of different types of households to explain the natural life cycle of amenities associated with gentrification. The natural life cycle of housing amenities is, as a matter of fact, a cycle of the capital, which is the core of the supply side of Marxism framework about gentrification. An empirical examination has been done in Lee & Lin's study following their hypothesis about the amenity life cycle. However, few following empirical studies examine the hypothesis afterwards.

2.4 The Role of Transit in Gentrification

2.4.1 Evidence of Transit-Induced Gentrification

The public investment, especially the public transit development, is one of the major suspected causes of the new round of gentrification after 2000. Several studies have already paid attention to that potential causal relationship. LeRoy & Sonstelie (1983) raised the first hypothesis that links gentrification with the transit development by introducing transit into the classical bid-rent curve in the traditional bid-rent theory. Specific studies to examine this causal relationship between transit and gentrification start from the 2000s, when the investment on high-quality transit accelerates significantly. Most of the following studies since the 2000s are empirical studies that examine the contribution of public transit, especially the rapid transit, to the re-emergence or acceleration of gentrification. Table 1 and 2 summarize the details of those studies. The studies that do not explicitly discuss gentrification are excluded from the two tables. For example, many studies have focused on the property value changes around the transit stations. However, due to their indefinite discussion on gentrification, these studies are excluded in this summary, even though the property change is one of the major indicators of gentrification.

There are in total 19 empirical studies focusing on the examination of gentrification until now, including two using qualitative methodology in the examination (Jones & Ley, 2016; Sandoval, 2018). As shown in Table 1, the definitions of gentrification vary among those studies, and most of the definitions are operational definitions that are established by the characteristics/indicators of gentrification. These definitions agree that gentrification is an upgrading process of the neighborhoods, appearing as more affluent residents with higher income or income potential, higher property values, and the upscaling of local commercials and retails. Among the 19 empirical studies, eleven clearly involved displacement when defining gentrification, including the two using qualitative methodology incorporating displacement-related questions into their interviews or semi-interviews (Danyluk & Ley, 2007; Jones & Ley, 2016; Baker & Lee, 2017; Deka, 2017; Dong, 2017; Lin & Chung, 2017; Sandoval, 2018; Chava et al., 2018; Chava et al., 2019; Chatman et al., 2019; Delmlle & Nilsson, 2020). Among the other nine using quantitative methodology, five used indicators of displacement as one of the indicators in the examinations of TIG (Jones & Ley, 2016; Baker & Lee, 2017; Deka, 2017; Lin & Chung, 2017; Chava et al., 2018; Chatman et al., 2019).

The operational definitions of gentrification in those studies determine their measures of gentrification. All of the 17 empirical quantitative studies except Lin's (Lin, 2002) used multiple indicators to examine the gentrification hypothesis in the transit-served areas. Those indicators (listed in Table 2) cover the housing, demographic, economic and transportation changes. Housing and demographic indicators are the most widely used measures of gentrification. Housing related changes include the changes of property density/quality/value/rent, and the percentage changes of owner/renter occupied units and the unit vacancy, as well as the building age. Among those indicators, the changes of property value and rent are the most commonly used indicators, with thirteen and nine studies out of the 17 quantitative empirical studies using them, respectively (Note: Chava et al. (2019) used the cross-sectional values). Demographic related changes are frequently used indicators as well. Among the demographic indicators, the percentage of higher-educated residents is the most frequently used one, and it is used in thirteen out of 17 studies. Other than the percentage of higher-educated residents, the population growth, percentage of the higher-educated, racial and ethnic compositions, and percentage of poverty/unemployed, growth of new residents, and percentage of the young are frequently used as demographic indicators as well. Dong (2017) and Chava et al. (2019) have also used the small-sized households or the household sizes as indicators of gentrification in their examination. Apart from housing and demographic indicators listed above, one of the economic indicators, or more likely to be the neighborhood income indicators—the household incomes are widely used by twelve out of 17 studies. In addition, Zheng & Kahn (2013) have used the count of new restaurants opening as an economic indicator to examine the TIG in Beijing. Moreover, some studies also use transportation indicators in the examination, such as the changes of households' private vehicle ownerships (Brown, 2016; Chava et al., 2019) and their commuting mode choices (Pollack et al., 2010; Brown, 2016; Baker & Lee, 2017; Chava et al., 2019). However, the transportation indictors are not used as widely as the other three categories of indicators.

Table 1 Empirical Studies of Transit-Induced Gentrification

Author (Year)	Location	Theory	Definition	Hierarchy of research design	Research method	Evidence
Lin (2002)	Chicago (1975-1991)	Explicit neoclassical location theory	Middle class resettlement of the inner city	***Cohort studies*** – use regressions for property value changes during 1975 – 80, 80 – 85, 85 – 91 by controlling property density, distance to CBD, and distance to lake.	***Regression:*** ***dependent variable*** – property value ***major independent variable*** – distance to the nearest transit stations	***Yes.*** Transit access was a spur to gentrification.
Kahn (2007)	14 MSAs (1970 – 2000)	Implicit neoclassical location theory (access to transit stations – "walk and ride" and "park and ride")	N/A (mainly defined by indicators of gentrification)	***Cohort studies*** – panel regression of home price changes and % of college graduates changes on two treatments (within "walk and ride" and "park and ride" transit station areas) with controlling year dummy, distance to CBD, and tract income above MSA 1970 median. It has also tested the longer adjusted periods with long differenced regressions by considering years close to transit stations.	***Regression (DID):*** ***two treatment –*** "park and ride" & "walk and ride" stations – (major dummy independent variables) ***dependent variable*** – home price changes and % of college graduates changes	***Varied among cities.*** Some cities, such as Boston and Washington, DC, have experienced gentrification in communities with increased access to rail transit, especially the communities treated with a new "walk & ride", but other cities are not significant, such as LA and Portland.

Table 1 Empirical Studies of Transit-Induced Gentrification (Continued)

Author (Year)	Location	Theory	Definition	Hierarchy of research design	Research method	Evidence
Danyluk & Ley (2007)	Toronto, Montreal & Vancouver, Canada (1971 – 2001)	Implicit neoclassical location theory (journey-to-work modes)	A process involving the movement of distinctive sections of the middle class into historically poor inner-city neighborhoods It typically includes housing renovation or redevelopment, rising property values, local retail upgrading, the transformation of local voluntary organizations and the displacement of long-established residents and small businesses.	***Cross sectional studies*** – The article takes a snapshot on the relationship between gentrification index and the journey to work shares in the neighborhoods in the cities in different periods.	***Description*** – Pearson correlation coefficients for gentrification index (1971 – 2001) against mode of travel to work by percentage (2001), controlling or not controlling the effects of distance from city center	***Not substantial.*** The more robust results reveal an overrepresentation of cycling to work in gentrified districts, and an underutilization of public transportation compared with other districts.
Pollack, Bluestone, & Billingham (2010)	12 transit-served metros among the 50 largest metropolitan areas with transit (1990 – 2000)	A theoretical. Only empirical analysis.	A neighborhood change process characterized by increasing property values and incomes	***Cross sectional studies*** – The article takes a snapshot on the population growth, racial and ethnic composition, total housing units, median household income, housing cost, public transit use for commuting, in-migration, and motor vehicle ownership for neighborhoods near commuter rail, heavy rail and light rails.	***Description*** – large difference analysis with the decade-long census data.	***Yes*** in neighborhoods initially dominated by rental housing and lower-income renters

Table 1 Empirical Studies of Transit-Induced Gentrification (Continued)

Author (Year)	Location	Theory	Definition	Hierarchy of research design	Research method	Evidence
Feinstein & Allen (2011)	Boston (1970 – 2000)	A theoretical. Only empirical analysis	The transition of a neighborhood's composition from relatively lower-income to relatively higher-income residents and business	***Cohort studies*** – The article uses longitudinal data, comparing the before and after effect of the transit on the % of new residence, higher educated, and household receiving public assistance, and mean family income, rate of change in avg. rent and aggregate value of owner occ. Homes between the treatment groups (neighborhoods within the transit station areas) and control groups (rest of Boston MSA).	***Description:*** % change every 5 years.	***Yes.*** This article verifies gentrification occurred along the transit stations, and it states the increased housing price would indicate the displacement of low-income residents.
Zheng & Kahn (2013)	Beijing, China (2007 & 2010)	Implicit neoclassical location theory – the gentrification happened in the undeveloped areas, and stating that the public and private investments (place-based amenity improvement) are capitalized into higher rent.	A process of upper-income resettlement and housing renovation in a geographical area that experiences an increase in the quality of private-sector economic activity as reflected by rising local home prices, new housing construction and new restaurants opening	***Cohort studies*** – the study use longitudinal data to detect the before and after gradient changes of indicators of gentrification as the distance to subway stations increases.	***Regression dependent variable*** – real estate prices; ***Spatial*** distribution (count) of housing supply and new restaurant openings; zone-level averages of income and years of schooling. ***major independent variable*** – distance to the nearest transit stations	***Yes.*** All indicators are supportive to the gentrification in the previous underdeveloped areas. This article also verified the displacement of "rural poor" in those gentrified areas.

Table 1 Empirical Studies of Transit-Induced Gentrification (Continued)

Author (Year)	**Location**	**Theory**	**Definition**	**Hierarchy of research design**	**Research method**	**Evidence**
Grube-Cavers & Patterson (2015)	Montreal, Toronto (1961 – 2006) & Vancouver (1981 – 2006), Canada	Implicit neoclassical location theory – Before discussing gentrification, the authors identified neighborhoods that were gentrifiable before gentrification, but it does not indicating any indicators of potential ground rent, and does not mentioned the capital flows.	Gentrification takes place in the neighborhoods that are considered "gentrifiable" (be poor or "working class"). For an area considered gentrifiable to gentrify, its social status (measured through income, education and percentage of residents in professional occupations) need to increase faster than that of the city. At the same time, rents and house values should be observed to increase faster than the city as a whole.	***Cohort studies*** – There are "treatment" in the survival analysis, and the treatment are defined as the "exposure" calculated as the distance to the nearest transit stations using gravity function	***Regression (Survival analysis)****:* ***major independent variable*** – distance to the nearest transit stations using gravity function	***Yes*** in Toronto and Montreal ***No*** in Vancouver (The neighborhoods already gentrified are excluded from the study, but still the gentrifiable neighborhoods are not identified as gentrified)

Table 1 Empirical Studies of Transit-Induced Gentrification (Continued)

Author (Year)	Location	Theory	Definition	Hierarchy of research design	Research method	Evidence
Brown (2016)	Los Angeles (2000 – 2013)	Implicit neoclassical location theory – accessibility improvements do add to house values, and gentrifiable here does not link to the distance to CBD, or any others indicating potential ground rent.	A process of neighborhood changes that results in economic and demographic transitions in transit-oriented neighborhoods	***Cohort studies*** **–** The study compares longitudinal changes between the transit adjacent communities with the less proximate neighborhoods.	***Description*** – % change and two-tailed t-test; Gentrification index (an aggregate of the changes); ***Regression*** to decide what types of neighborhoods changes most***:*** ***dependent variable*** – gentrification index ***major independent variables (level in 2000) –*** race or ethnicity, education, median households income, housing units-renter-occupied (%), median rent, median house value	***Yes.*** BRT station areas could experience gentrification as well, and economic preconditions rather than racial-ethnic makeups are better predictors of neighborhood change and markers of neighborhoods' potential to gentrify.
Jones & Ley (2016)	Vancouver (2013 – 2014)	A theoretical – only empirical analysis.	N/A In the study, the authors interpret gentrification as the appreciation of property value/rent, and the demographic changes, such as the displacement of vulnerable immigrants and refugees.	***Cross-sectional study*** **–** The study use 12 semi-structured interviews and four focus groups with 26 residents to conduct a qualitative study on the gentrification along two transit neighborhoods – Richmond Park and Maywood residents	***Qualitative study*** – 12 semi-structured interviews and four focus groups with 26 residents in total	***Yes.*** The information by the qualitative analysis verifies the appreciation of apartment rent, and the potential displacement concerns of some interviewees.

Table 1 Empirical Studies of Transit-Induced Gentrification (Continued)

Author (Year)	Location	Theory	Definition	Hierarchy of research design	Research method	Evidence
Baker & Lee (2017)	14 US urbanized areas (UAs)	Explicit Marxism – supply- and demand- side theories of gentrification.	A process of neighborhood change characterized by neighborhood upgrading coupled with residential displacement. The authors view displacement as an inherent part of gentrification and not a consequence, separate from the process.	***Cohort studies*** – The study use longitudinal change data, and use spatial autoregressive lags to indicating the treatment and control groups for the examination of gentrification along the transit stations.	***Regression (spatial autoregressive lag models):*** ***dependent variable*** – neighborhood changes ***major independent variable –*** LRT station buffer (The weight matrix in the SAR is Queen weight matrix)	***Not prevalent.* E.g.,** Yes in San Francisco and Denver, but no in Portland, Los Angeles, and Buffalo.
Dong (2017)	Suburban Portland (1990 – 2014)	A theoretical – the study states that the previous studies has focused on the private actors (Neoclassical) and capital (Marxism), but there are much fewer studies have addressed the role of public transit (maybe a new theory?)	A class-based phenomenon whereby low-income households are displaced by middle- and high-income households in combination with the reinvestment of the built environment	***Cohort studies*** – The study utilized longitudinal quasi-experimental design to do pre-test and post-test, by comparing between treatment groups and control groups selected by propensity score matching. This is a substantial study.	***Description (DID):*** pretest-posttest comparisons by t-test between treatment and control/average groups on the indicators of gentrification, including household income, minority population, home value, and housing tenure.	***No.*** This conclusion is consistent with other studies (Kahn, 2007; Baker & Lee, 2017) that there is no TIG in suburban Portland.

Table 1 Empirical Studies of Transit-Induced Gentrification (Continued)

Author (Year)	Location	Theory	Definition	Hierarchy of research design	Research method	Evidence
Deka (2017)	New Jersey (1990 - 2013)	Implicit neoclassical – It states the areas near rail stations will experience a significant increase in the demand for housing, and may raise housing value, reduce transportation cost. It does not mention anything about the capital flows.	N/A The term gentrification in this study focus more on the property value appreciation, but concerns more over the potential displacement of the low-income and minorities. It examines displacement as well in its quantitative examinations.	***Cohort studies –*** The study use longitudinal data to examine the before and after changes between treatment and control groups from the macro- and micro- levels.	***ANOVA :*** ***Macro-level*** – between the tracks within a half mile of rail stations and the tracts beyond that distance ***Micro-level*** – between the tracks where the stations are located with the remaining tracts within the municipalities that have commuter rail stations ***Regressions:*** ***dependent variable*** – medians and median changes of home value and rent ***major independent variable*** – dummy variable for station proximity.	***No.*** It finds that the home value and increase in home value is higher during the study period in the areas near stations than in the areas beyond, but similar evidence is not found for rent. Moreover, this study shows no evidence of changes that might be construed as having potential for the displacement of minority populations. It also concludes that keeping rent low by increasing supply of rental units would reduce the potential for displacement in the future.

Table 1 Empirical Studies of Transit-Induced Gentrification (Continued)

Author (Year)	**Location**	**Theory**	**Definition**	**Hierarchy of research design**	**Research method**	**Evidence**
Chava, Newman & Tiwari (2018)	Bangalore, India (June 2015)	Implicit Marxism – stating the metro station areas are witnessing the influx of large capital on condominiums.	The influx of capital in an inhabited or vacant area, leading to the direct or exclusionary displacement of existing residents, and socioeconomic upgradation of the area	***Cross-sectional studies*** – The study used a door-to-door survey with a sample size as 10% of the overall population on June 2015, and compared the gentrification between new- and old-TOD builds and , as well as the travel behaviors between gentrifiers and non-gentrifiers.	***Regression:*** ***dependent variable*** – transit ridership ***major independent variable*** – TOD gentrification	***Yes.*** Higher percentage of gentrifiers use public transit
Chava, Newman & Tiwari (2018)	Bengaluru, India (2012-2014)	Implicit Marxism – assuming that the large-scale influx of public and private capital lead to gentrification in TODs.	New-build gentrification: the new TOD investment lead to exclusionary displacement (instead of direct displacement of pre-existing residents), and change in social composition and indirect displacement of the poor due to price shadowing. Old-build gentrification: move-in of gentrifiers attracted by the large investments, displacing the neighborhood's residents from their traditional old residential area.	***Cross-sectional studies –*** The study used the data from a private organization covering all the condominiums under various stages of construction in a three-year period (2012-2014), and examined the cross-sectional levels of indicators of gentrification for new- and old-build TOD residents, as well as newly moved residents and the residents staying for long in old residential area to examine the gentrification (more likely to be displacement) of them.	***Description:*** 1) Means and variances of indicators of gentrification; 2) Means tests of indicators of gentrification between new- and old-build TOD residents; 3) Means tests of indicators of gentrification between newly moved residents and the residents staying for long in old residential area.	***Yes.*** The new housing projects in TODs are causing new-build gentrification, but the old build existing housing remains ungentrified.

Table 1 Empirical Studies of Transit-Induced Gentrification (Continued)

Author (Year)	**Location**	**Theory**	**Definition**	**Hierarchy of research design**	**Research method**	**Evidence**
Bardaka, Delgado, & Florax (2018)	Denver, CO (1990-2000) (The Dever Light rail system opened in 1994)	Explicit neoclassical location theory – "capitalization of accessibility benefits"	Hypothesis of TIG: an increase in socioeconomic indicators, such as income, educational attainment, and housing values in the neighborhoods close to urban rail station locations capture the essence of residential gentrification.	***Cohort studies*** – The study utilized longitudinal quasi-experimental design to do post-treatment tests, through a spatial difference-in-difference model. Adding spatial dependence in the DID models captures both direct and indirect (spatial spillover) effects of urban rail.	***Spatial Difference-in-Difference (DID) Regression:*** ***dependent variable* –** four indicators of gentrification: household income, education attainment, managerial occupation, and housing value (panel data model include the levels in both years) ***major independent variable* –** treatment dummy of whether served by rail transit (if yes, 1).	***Yes.*** Higher household income, housing value, and managerial occupation with complexity for different buffers of distance to urban rail stations, but no significant impact on education attainment.

Table 1 Empirical Studies of Transit-Induced Gentrification (Continued)

Author (Year)	**Location**	**Theory**	**Definition**	**Hierarchy of research design**	**Research method**	**Evidence**
Delmlle & Nilsson (2020)	United States (1970 – 2014)	Explicit of neoclassical location theory – "Transportation, and the accessibility it enables, has long held a prominent place in neoclassical economic theories explaining the residential sorting of individuals by income across urban areas"	TIG hypothesis: The development of rail transit will place an upward pressure on land and housing values and that higher-income residents will outbid low-income residents for this new amenity. Hypothesis of TIG-displacement: Low-income residents disproportionately move out of neighborhoods in close proximity to new rail transit stations. This study defined the TIG more likely to displacement, which means it mainly examined the displacement perspective of the gentrification.	***Cohort studies –*** The study used the Panel Study on Income Dynamics (PSID) dataset to examine the residential mobility five year before and after the rail transit station opened.	***Multi-level logistic Regression (individual, neighborhood, and county levels):*** ***dependent variable*** – a residential move out of a census tract reported by an individual ***major independent variable*** – 1) dummy variable of whether the census tract has a rail transit station or about to have; 2) low-income indicator (binary); 3) cross-product of 1) and 2).	***No.*** Individuals, on average, do not have statistically different odds of leaving a transit neighborhood as compared with other neighborhoods. TIG is a more recent phenomenon. The transit-induced displacement of low-income residents in the U.S. is not statistically significant.

Table 1 Empirical Studies of Transit-Induced Gentrification (Continued)

Author (Year)	**Location**	**Theory**	**Definition**	**Hierarchy of research design**	**Research method**	**Evidence**
Lin & Chung (2017)	Taipei City, Taiwan (1996 – 2013)	Both. Explicit neoclassical location theory is examined by indicators of gentrification: migration (share of residents moving in or out) and education attainment (share of college graduates), whereas Marxism rent gap theory is examined by indicators of gentrification: new floor (relative increased floor area) and housing price (standardized housing price (i.e., housing price per Ping)).	Gentrification is a class-upward process of the move-in of people and businesses who can afford higher land costs and displace pre-existing low-income families and small businesses. Gentrifiable area is defined as the area with a below average social status that could be measured through income, education, or percentage of residents in professional occupations.	***Cohort studies –*** The study uses longitudinal data to examine the impact of the distance to nearest metro station on gentrification outcomes.	***Regression (panel and OLS)*** ***dependent variable*** – Gentrification outcomes: migrate, education attainment, new floor, and housing price ***major independent variable*** – travel distance to the nearest metro transit station, and distance to CBD (to examine the differences of TIG between inner city and outer city areas)	***Yes.*** Metro-induced gentrification revealed by highly educated residents and real-estate development was significantly stronger in the outer city areas, whereas metro-induced gentrification revealed by house prices was significantly stronger in the inner city areas.

Table 1 Empirical Studies of Transit-Induced Gentrification (Continued)

Author (Year)	**Location**	**Theory**	**Definition**	**Hierarchy of research design**	**Research method**	**Evidence**
Chatman et al. (2019)	California (Los Angeles, San Jose, and San Francisco (1990 – 2013)	Implicit neoclassical location theory that assumes the proximity to rail stations will be capitalized with higher housing price and rent.	N/A Operational definition of gentrification is the experience of an increase in the share of higher income households in the census tracts near rail stations. It stresses the neighborhood change and displacement, other than the concept of gentrification.	***Cohort studies –*** The study uses longitudinal data to examine the impact of the TIG on driving. This is not a study that specifically examined TIG, but it is built on the TIG hypothesis.	***Tobit Regression models: dependent variable*** – Household Daily VMT ***major independent variable*** – Household income	***Yes.*** The rail station served neighborhoods that underwent gentrification between 1990 and 2013 are typically increased in population (and sometimes increased even the population of lower-income households, despite gentrification). The driving reduction of high-income households in the TIG neighborhoods are either the same, or more in response to rail proximity than lower income households.

Table 1 Empirical Studies of Transit-Induced Gentrification (Continued)

Author (Year)	**Location**	**Theory**	**Definition**	**Hierarchy of research design**	**Research method**	**Evidence**
Sandoval (2018)	California (Oakland, Los Angeles, and San Diego). (2012 – 2016)	A theoretical. Only empirical analysis.	N/A Gentrifiability (or susceptible to gentrification) is operationally defined as low-income neighborhoods with disproportional people of color. Gentrification is not specifically defined, but implicitly implied as the move-in of more affluent population and the displacement of previous low-income and people of color.	***Cross sectional studies –*** As a case study, this study presented three cases to document the collective actions (based on ethnic identity) against transit-oriented, development-induced gentrification in three Latino barrios.	***Qualitative Methodology (Critical Case study & Revelatory Case Study) –*** this study used a multiple-site case study in California to examine how Latino ethnic identity is itself a driving force in unifying barrio residents, neighborhood activists, and local politicians in resisting large-scale transit-induced redevelopment projects that threaten to gentrify the neighborhoods. In depth interviews are taken on 70 stakeholders who were directly involved in these TOD projects. These interviewees are involved through a snowball sampling method, including neighborhood faith-based leaders, local politicians, housing and commercial developers, local small business owners, urban planners, and activists.	***Yes.*** This study has verified (or is built on) the TIG pressure, and documented that ethnic identity helped Latinos in the Latino barrios create meaningful spaces of participation that transformed the transit investment into community-driven projects and encouraged opportunities for community benefits.

Table 2 Measures of Gentrification in the Studies of Transit-Induced Gentrification

Author (year)	**Measures**					
	Housing					
	Property value changes / housing price / affordability	Rent changes / rent burden	House area	% of owner /rent-occupied dwellings changes	Housing units changes /vacant dwellings	Building age
Lin (2002)	✓					
Kahn (2007)	✓					
Danyluk & Ley (2007)						
Pollack, Bluestone, & Billingham (2010)	✓				✓	
Feinstein & Allen (2011)	✓	✓				
Zheng & Kahn (2013)	✓	✓			✓	
Grube-Cavers & Patterson (2015)		✓		✓		
Brown (2016)	✓	✓		✓	✓	
Baker & Lee (2017)	✓	✓				
Dong (2017)						
Deka (2017)	✓	✓			✓	
Chava, Newman & Tiwari (2018)	✓	✓	✓	✓	✓	
Chava, Newman & Tiwari (2019)	✓	✓	✓	✓	✓	✓
Bardaka, Delgado, & Florax (2018)	✓					
Delmlle & Nilsson (2020)	✓	✓				
Lin & Chung (2017)	✓		✓			
Chatman et al. (2019)						
Frequency (16)	**13**	**9**	**3**	**4**	**6**	**1**

Table 2 Measures of Gentrification in the Studies of Transit-Induced Gentrification (Continued)

Author (year)	Measures			
	Demographic			
	Population growth /density	% of college graduates or other indicators about education	% of affluent /professional employees	In-migration /new residents / time of stay
Lin (2002)				
Kahn (2007)		✓		
Danyluk & Ley (2007)		✓	✓	
Pollack, Bluestone, & Billingham (2010)	✓			✓
Feinstein & Allen (2011)		✓		✓
Zheng & Kahn (2013)	✓	✓		
Grube-Cavers & Patterson (2015)		✓	✓	
Brown (2016)	✓	✓		
Baker & Lee (2017)	✓	✓	✓	
Dong (2017)		✓		
Deka (2017)		✓		✓
Chava, Newman & Tiwari (2018)		✓	✓	
Chava, Newman & Tiwari (2019)		✓	✓	✓
Bardaka, Delgado, & Florax (2018)		✓	✓	
Delmlle & Nilsson (2020)		✓		
Lin & Chung (2017)			✓	✓
Chatman et al. (2019)	✓			✓
Frequency (16)	**5**	**13**	**7**	**6**

Table 2 Measures of Gentrification in the Studies of Transit-Induced Gentrification (Continued)

Author (year)	**Measures**			
	Demographic			
	Racial and ethnic composition	% of poverty /unemployed or household receiving public assistance	% of young population / age distribution	% of small-sized households / household size
Lin (2002)				
Kahn (2007)				
Danyluk & Ley (2007)				
Pollack, Bluestone, & Billingham (2010)	✓			
Feinstein & Allen (2011)		✓		
Zheng & Kahn (2013)				
Grube-Cavers & Patterson (2015)				
Brown (2016)	✓			
Baker & Lee (2017)	✓	✓		
Dong (2017)	✓		✓	✓
Deka (2017)	✓	✓	✓	
Chava, Newman & Tiwari (2018)		✓	✓	
Chava, Newman & Tiwari (2019)		✓	✓	✓
Bardaka, Delgado, & Florax (2018)				
Delmlle & Nilsson (2020)				
Lin & Chung (2017)				
Chatman et al. (2019)				
Frequency (16)	**5**	**5**	**4**	**2**

Table 2 Measures of Gentrification in the Studies of Transit-Induced Gentrification (Continued)

Author (year)	Measures			
	Economic		Transportation	
	Household income	Count of new restaurants opening	Household income	Count of new restaurants opening
Lin (2002)				
Kahn (2007)				
Danyluk & Ley (2007)				
Pollack, Bluestone, & Billingham (2010)	✓		✓	
Feinstein & Allen (2011)	✓		✓	
Zheng & Kahn (2013)	✓	✓	✓	✓
Grube-Cavers & Patterson (2015)	✓		✓	
Brown (2016)	✓		✓	
Baker & Lee (2017)	✓		✓	
Dong (2017)	✓		✓	
Deka (2017)	✓		✓	
Chava, Newman & Tiwari (2018)	✓		✓	
Chava, Newman & Tiwari (2019)	✓		✓	
Bardaka, Delgado, & Florax (2018)	✓		✓	
Delmlle & Nilsson (2020)				
Lin & Chung (2017)				
Chatman et al. (2019)	✓		✓	
Frequency (16)	**12**	**1**	**12**	**1**

Based on different indicators of gentrification, those 19 studies have used different study designs to examine the TIG. With regard to the hierarchy of evidence in science (Greenhalgh, 1997; Yetley et al., 2017), thirteen out of 19 studies can provide cohort evidence (i.e., use cohort designs), and the others can only provide cross-sectional evidence (i.e., use cross-sectional designs).

The cohort studies compared the longitudinal changes of the indicators of gentrification between the "treatment" and control groups. Among the 17 quantitative empirical studies, most used regressions models to examine the differences between treatment and control groups, and some used the descriptive statistics of the indicator changes (Feinstein & Allen, 2011; Dong, 2017). Some of the regression models tested the TIG by examining the significance and magnitude of the impact of distance to the nearest transit stations on the indicators of gentrification, in another word, the distance-decay impact of the transit-stations (e.g., Lin, 2002; Zheng & Kahn, 2013); whereas some other studies used difference-in-difference regression models to compare the treatment and control groups for their pretest-posttest of transit station opening (e.g., Kahn, 2007; Bardaka, Delgado, & Florax, 2018). These regression analyses vary in their emphases in choosing or building up the models. For example, some of them emphasized the spatial dependence of the occurrence of TIG, and they incorporated spatial lags into their regression models (Baker & Lee, 2017; Bardaka, Delgado, & Florax, 2018), or used survival analysis using the exposure as a major independent variable, which was calculated as the distance to the nearest stations within the gravity function (Grube-Cavers & Patterson, 2015). Delmlle and Nilsson (2020) emphasized the impact of the characteristics of areas downward the spatial hierarchy, so the multi-level logistic regression was used with classifying independent variables into individual, neighborhood, and county levels.

Even though all the thirteen studies used cohort designs, they performed differently in controlling the risk of statistical bias in the examination of the causal relationship between transit and gentrification, based on the bias assessment criteria raised by Padeiro et al. (2019). The bias assessment criteria included twelve criteria concerning about the control groups used for comparisons, and the consideration of endogeneity, spatial autocorrelation, spillover effects, gentrifiability, built environment, transit performance/quality/connectivity, time, and choice of distance type and threshold, as well as the robustness (sensitivity test) and the quality of the analysis. These thirteen studies met different bias assessment criteria, and three studies performed relatively better, with fully satisfying or partly satisfying about five bias assessment criteria (Baker & Lee, 2017; Dong, 2017; Bardaka, Delgado, & Florax, 2018).

Except the thirteen studies using cohort designs, other studies used cross-sectional designs to examine the TIG, by taking a snapshot on the relationship between transit development and gentrification. Most of those studies used methods of descriptive statistics in the examination, and some studies applied means tests. For example, due to the limitation of data source in India, Chava et al. (2018) utilized the 10% survey data to compare the travel behaviors between gentrifiers and non-gentrifiers, in order to examine whether the gentrification is caused by transit; and Chava et al. (2019) used a database of households within the study area from a private organization to take a snapshot and comparison of indicators of gentrification between the new- and old-build TOD housing residents, and between the residents of newly moved-in and the residents staying longer. Apart from those empirical studies using quantitative methods, Jones & Ley (2016) provided cross-sectional evidences by qualitative designs, including 12 semi-structured interviews, and 4 focus groups, for the examination of the TIG and displacement concerns; whereas Sandoval (2018) used critical case study and revelatory case study with three mini-cases, 70 in-depth interviews for examining the role of Latino ethnic identity in resisting large-scale transit-induced redevelopment projects that threatened to gentrify the neighborhoods.

These examinations of TIG hypothesis have reached different conclusions. Of the 19 empirical examinations, twelve have verified that the transit access can somehow trigger gentrification, three have not found substantial evidence of TIG, and four have concluded that TIG is not prevalent among cities. Two of them concluded that there was no TIG in suburban Portland and New Jersey (Dong, 2017; Deka, 2017), and that result was consistent with two of studies that concluded the non-prevalent results (Kahn, 2007; Baker & Lee, 2017). In addition, Delmlle and Nilsson (2020) examined the displacement as the major measure of gentrification in transit-served neighborhoods from 1970 to 2014, and found that displacement (i.e., TIG in his operational definition) is likely to be a more recent phenomenon, and the displacement of low-income households is not statistically significant. Danyluk and Ley (2007) found that the gentrified districts have "underutilization" of public transit than other districts, indicating that the gentrification might not result from transit development. To summarize, the empirical examinations of TIG hypothesis have drawn variable conclusions. This variability of conclusions could result from either the mediating factors such as the regional and local characteristics or from the use of different operational definitions and measures of gentrification, research designs, or methods (Brown, 2016; Zuk et al., 2017; Bardaka et al., 2019). Among those empirical studies of TIG, only Brown's study has examined the types of neighborhoods that changes most after the transit stations opening with a regression model (Brown, 2016). The results of the model have shown that the economic preconditions rather than racial-ethnic makeups are better predictors of neighborhoods' potential to gentrify.

In addition, among the 19 empirical studies, only Brown's study focused on the Bus Rapid Transit (BRT), and all others focused on the rail transit such as light rail and heavy rail (Brown, 2016). BRT, running on rubber tires, requires less capital investment and fixed infrastructure, and costs less to change routes than rail transit (i.e. less stable transit service). Therefore, residents could be less likely to invest in real estate along BRT than rail transit, and thus the probability of TIG around BRT stations could be lower than that around rail stations. However, no empirical examinations have compared the performances of BRT and rail transit in inducing gentrification.

2.4.2 Explanations of Transit-Induced Gentrification

Based on these empirical studies, scholars have also developed fundamental explanations of the gentrification near transit. Revington (2015) raised the term "Transit-Induced Gentrification" to summarize the previous descriptions of gentrification induced by public transit development, such as transit-served neighborhoods (Lin, 2002), transit-oriented communities (Kahn, 2007) and transit-rich neighborhoods (Pollack et al., 2011). After that, transit-adjacent areas (Brown, 2016), TOD gentrification (Baker & Lee, 2017; Dawkins & Moeckel, 2016; Sandoval, 2018), transit-related gentrification (Deka, 2017), transit-oriented gentrification (Chatman et al., 2019), and metro-induced gentrification (Lin & Chung, 2017) were used as well to describe the gentrification around transit stations, but these terms were rarely followed by other studies afterwards, and "Transit-Induced Gentrification" was the one used most commonly. The term "Transit-Induced Gentrification" was first clearly defined by Dawkins & Moeckel (2016) as "the phenomenon that occurs when transit proximity is capitalized into TOD housing prices, resulting in higher income households outbidding lower income households for housing in transit proximate locations". Tehrani et al. (2019) summarized the neighborhood changes as "upscaling" and defined Transit-Induced Gentrification as "a phenomenon whereby the provision of transit service, such as LRT, and associated area of development change in the direction of neighborhood 'upscaling'."

Revington (2015) has tried to utilize the traditional gentrification theories—the neoclassical economic framework and Marxism framework—to analyze how transit influences the recent gentrification (Figure 1). Based on the neoclassical economic framework, he subsumed transit development in the Location Theory and hypothesized that the higher accessibility brought by new transit is capitalized to land value, and thus induces gentrification. In contrast, based on the Marxism framework, he subsumed transit development in the Rent Gap Theory and hypothesized that the new transit triggers the investment from capitalists and landlords to close the gap between the current capitalized ground rent and the potential ground rent.

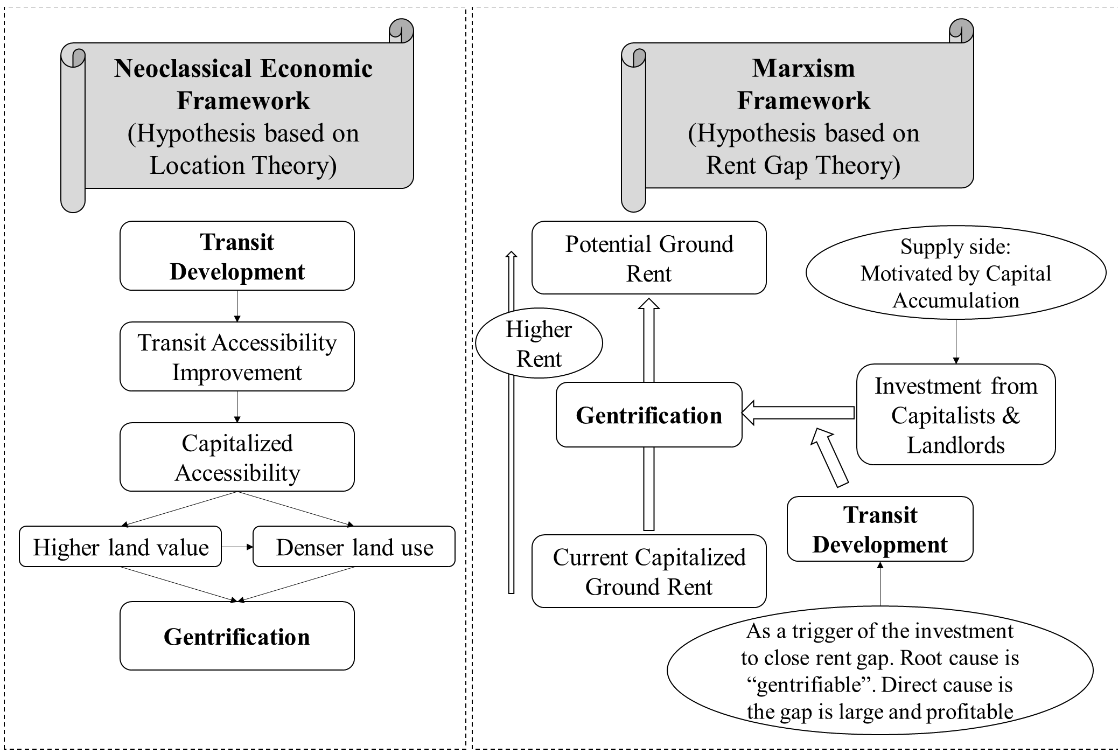

Figure 2 Hypotheses Explaining Transit-Induced Gentrification

These two hypotheses of subsuming transit in the traditional theoretical frameworks of gentrification have been followed by 14 out of the 19 empirical studies of TIG explicitly and implicitly (listed in Table 1). Among the 14 studies, three explicitly followed the hypothesis under neoclassical economic framework alone (Lin, 2002; Bardaka et al., 2018; Delmlle & Nilsson, 2020), one explicitly followed the hypothesis under Marxism framework of gentrification (Baker & Lee, 2017), and one explicitly followed both of the hypotheses (Lin & Chung, 2017). Seven studies implicitly followed the hypothesis under neoclassical economic framework (Kahn, 2007; Danyluk & Ley, 2007; Zheng &Kahn, 2013; Grube-Cavers & Patterson, 2015; Brown, 2016; Deka, 2017; Chatman et al., 2019), whereas only two implicitly followed the hypothesis under Marxism framework (Chava et al., 2018; Chava et al., 2019). Pandeiro et al. (2019) reemphasized the two hypotheses of explaining TIG, and raised another two hypotheses for the explanation, both suggesting that gentrification could be associated with the endogeneity of TOD. The first hypothesis suggests that gentrification is a by-product of the newly built transit, under the TOD policies. This means the intentions of TOD policies have already included attracting private-led investment to the upgrade the neighborhoods, and some new or upgraded dwellings are targeted on the upper-income households (Cappelano & Spisto, 2014), the one-person households, and the young professionals (Rayle, 2015). The other hypothesis is in reverse, saying that the transit design prefers the neighborhoods that are already experiencing the upgrading process, especially in the social composition of the neighborhood, and the causative relationship is then reversed, saying that TOD is actually a consequence of gentrification (Pandeiro et al., 2019).

Other than these four hypotheses of explaining TIG, some studies also have discussed the pushing and pulling effects of transit on the residents' location choice, which is critical for the move-in and move-out during gentrification. The amenity improvement resulting from the TOD could attract affluent residents to move in. The residents moving-in then could accelerate the capitalization of transit accessibility into housing values. However, the higher housing price, heightened noise, pollution, and traffic around the transit stations would keep the residents away (Zuk et al., 2015; Zuk et al., 2017; Cervero, 2010; Kilpatrick et al., 2007; Deka, 2017). Furthermore, some studies have summarized the pre-conditions of the presence of TIG: 1) the neighborhood near transit stations is "gentrifiable"—with a high proportion of low-income renters, the lower-than-average incomes, the lower overall education attainments, and more carless households (Brown, 2016; Grube-Cavers & Patterson, 2015); 2) the new transit station could provide a "viable", cheaper and time-saving alternative to the private vehicles (Zuk et al., 2015; Brown, 2016); and 3) a credible commitment of large scale investment is made on the physical environment and housing amenities by the government, financial institutions, or developers (Zuk et al., 2015; Coleman, 2012).

Other than the studies focusing on either the empirical evidences or the fundamental explanations of the TIG, some studies have explored the relationship between transit development and gentrification or displacement from some other perspectives. Dawkins & Moeckel (2016) analyzed the impact of TOD-based affordable housing policies on the displacement of low-income households along the transit corridors, with a case study of Washington DC by a simulation approach—the Simple Integrated Land Use Orchestrator (SILO) model. They verified that the consequences of the affordability restrictions on the new dwellings constructed in TOD areas could include the effective promotion of housing affordability, the improvement of transit accessibility to low-income households, and the reduction of the extent of TIG. Barton & Gibbons (2017) examined whether high- or low-income households are more attracted by the public transit in New York City. Their cross-sectional analysis showed the lower-income households' concentration was more corresponded to higher concentration of bus stops, but the longitudinal analysis indicated that it was only the median household income changes rather than other neighborhood changes were associated with the concentration of different forms of transit. Fan & Guthrie (2012) explored resident perceptions of transit-induced neighborhood changes, with a survey in 16 selected neighborhoods within the station areas. Their ordered probit regression models verified residents' generally positive perceptions of the transit-induced neighborhood changes, and they found that the less affluent groups (including African Americans, immigrants, frequent transit users, and carless residents) and new residents had more positive perceptions of those transit-induced changes, but the Asian urbanities had perceptions that were more negative. Chatman et al. (2019) examined the impact of Transit-Oriented Gentrification on driving, using the Tobit regression models with setting the distribution of household daily vehicle miles traveled (VMT) (i.e. dependent variable) as left-truncated. Their analysis found that the rail access usually had no independent impact on households' driving, but could have impact through the gentrification/displacement in the rail-served neighborhoods, and the displacement would either reduce driving or have no significant effect. They also found that higher-income households were more likely to reduce their driving the same or more in response to rail proximity than the lower-income.

Four literature reviews have analyzed the role of high-quality public transit—both rails and buses—in spurring gentrification and displacement, and have discussed about the variability of the conclusions (Zuk et al., 2015; Zuk et al., 2017; Tehrani et al., 2019; Padeiro et al., 2019). Through reviewing the literature of the relationships between transit and gentrification, Zuk et al. (2015; 2017) pointed out the variability in the examination results on TIG could due to some mediating factors such as housing tenure and type, the methodology limitations and the negligence of different displacement forms. Padeiro et al. (2019) reviewed a pool of TIG literature selected by a systematic protocol. They found the current TIG literature gave different conclusions of the occurrence of TIG, even in the same place. For example, current literature have inconsistent TIG findings for the same cities, such as Denver, Dallas, Los Angeles, Pittsburgh, Portland, San Diego, and St. Louis. They argued that the variability of conclusion could result from the differences in the risk of statistical bias of the studies. To be more specific, they developed a set of bias assessment criteria to appraise the quality of the current studies of TIG, and found these studies perform differently in controlling the risk of statistical bias, which could be one of the causes of the variability of conclusion. Tehrani et al. (2019) mainly discussed about the negative impacts of the TIG on health (e.g., health inequities and inequalities) through their literature review, especially among the communities of color, instead of exploring reasons of variable results in TIG examination. To be more specific, the three perspectives of the impact of TIG in communities of color—residential displacement, cultural displacement, and disruption of local community ties—could lead to psychological distress, and feeling of isolation, warning social health. In addition to those literature reviews on TIG, Rayle (2015) explored the connections between TOD and displacement, and raised four hypotheses to explain why few evidence has been found for the displacement induced by transit development, including the methodological flaws in displacement studies, the neglect of different social and psychological forms of displacement, the potential transportation cost savings to balance housing cost in the tradeoff, and the local policies to prevent gentrification/displacement.

2.5 Discussions and Conclusions

As summarized in the previous sections, studies of the Transit-Induced Gentrification (TIG) emerge after the 2000s, during the period when some new features of gentrification appear and more fundamental and empirical studies are conducted to explain and examine those new features. The number of studies specifically about TIG has grown consistently and now there are nineteen empirical and four review articles. These studies report and confirm variable findings, which suggest the need for further work. To summarize, there are mainly three major unresolved issues about the TIG in development of theory and explanation of outcomes that require additional study.

First, among the current empirical studies, TIG has been found significant in some cities, but insignificant in some other cities, and some studies found variable evidence. These different conclusions can in part result from the statistical bias, which refers to use of an estimate that is not the true estimate because of theoretical, methodological, or other limitation that reduce the validity of the results (Padeiro et al., 2019). To be more specific, the current empirical studies of TIG have used different operational definitions and indicators of gentrification, as well as the different research designs for the examination of TIG, and these differences have raised the risk of statistical bias in drawing conclusions about the pervasiveness of TIG. Therefore, a systematic examination of the TIG hypothesis with consistent definition and indicators of gentrification as well as the same research design is needed.

Second, few empirical studies have tested the fundamental hypotheses of TIG, as well as the associated factors that could affect the probability of TIG. Until now, only Revington (2015) has tried to explain TIG under two traditional gentrification theory frameworks—Neoclassical economic framework such as the Location Theory and Marxism framework such as the Rent Gap Theory. Revington (2015) has suggested hypothesis under the Marxism framework for TIG after his analyses, since that the Marxism framework recognizes the class conflicts and the impact of existing legacy on the capital investment. However, only three out of 19 empirical studies of TIG have followed the Marxism framework by their arguments explaining TIG but not by measures or examinations of TIG. In contrast, ten out of 19 empirical studies have built on the neoclassical location theories, some by their arguments explaining TIG and some by their using accessibility as one of the indicators of TIG. One study has used indicators from both of the frameworks to measure gentrification (Lin & Chung, 2017). Among these 14 studies, only five have explicitly mentioned the fundamental hypotheses of TIG, but none of them has examined the fundamental hypotheses, such as changes of the commuting modes, the consumption preferences, or the decision-making process of developers (Lin, 2002; Baker & Lee, 2017). In addition, few studies have systematically examined the impact of the regional and local factors on the occurrence and magnitude of TIG as well. It would be more supportive for the theoretical development on the TIG, if there were more substantial empirical evidences of the factors that affect the probability of TIG.

Third, similar to the traditional gentrification studies, current TIG studies diverge on the role of displacement in TIG, with some studies including the displacement as an essential or required element of gentrification and some not. Displacement is included in the operational definitions of gentrification in eleven of the 19 definitions of TIG,d two of which are qualitative studies (Danyluk & Ley, 2007; Jones & Ley, 2016; Baker & Lee, 2017; Deka, 2017; Dong, 2017; Lin & Chung, 2017; Sandoval, 2018; Chava et al., 2018; Chava et al., 2019; Chatman et al., 2019; Delmlle & Nilsson, 2020). Among the nine quantitative studies, five have used indicators of displacement in the examination of TIG (Baker & Lee, 2017; Deka, 2017; Lin & Chung, 2017; Chava et al., 2019; Chatman et al., 2019). Therefore, it is still unsettled that whether displacement should be viewed as an essential element or a potential but not necessary result of the TIG.

To make a progress in the exploration of TIG, this dissertation is designed to answer two questions by a consistent research design and methodology for all areas that are newly served by rapid transit from 2000 through 2009 in the U.S. The two research questions are: 1) *Do Rapid Transit Lines Induce Gentrification in U.S. Metropolitan Areas (MSAs)?*, and 2) *what factors affect the occurrence of Transit-Induced Gentrification (TIG) in U.S. MSAs?*

Chapter 3: Do Rapid Transit Lines Induce Gentrification In U.S. MSAs?

3.1 Introduction

Gentrification in this study is defined as the upgrading and changes that occur in lower-income and/or minority neighborhoods with the influx of more affluent residents who usually are disproportionately white, the associated increases in property values, the renovation of housing, the upscaling of local commercial and retail properties, and potentially, the displacement of current residents (Table 3). The “upgrading” in this definition of gentrification is consistent with previous definitions in the literature (e.g., Varady, 1986; Teernstra & Gent, 2012), referring to the physical and social improvement of the neighborhood and usually named as “neighborhood upgrading”. The neighborhood upgrading, however, is generally broader than gentrification, because unlike gentrification, the neighborhood upgrading does not limit the attribute of the neighborhood before the upgrading process. Therefore, gentrification could be viewed as one among several forms of neighborhood upgrading (Teernstra & Gent, 2012).

The term Transit-Induced Gentrification (TIG) is used to describe the phenomenon that the opening of new rapid transit stations could induce gentrification in the neighborhoods that are newly served by those rapid transit stations. As summarized in Chapter 2, previous empirical studies have variable findings in their examinations of the hypothesis of TIG. This variability in findings could result from the non-pervasiveness of TIG across different cities or metropolitan statistical areas (MSAs), but it could also be partly caused by the inconsistent definitions and measures of gentrification in those empirical studies, as well as the various study designs. For example, Padeiro et al. (2019) have reported that the empirical studies on the examination of TIG hypothesis found consistent evidence of TIG in some cities such as San Francisco (TIG detected) and Baltimore (no signs of TIG), but also found inconsistent evidence in some other cities such as Denver, Dallas, Los Angeles, Pittsburgh, Portland, San Diego, and St. Louis. They suspected that the inconsistent evidence could in part result from the different risk of statistical bias of those empirical studies, based on the quality appraisal of those studies. Given these findings and the debate over the prevalence of TIG and the factors that contribute to it, additional study is needed.

This chapter is designed to test the TIG hypothesis using a quasi-experimental design with consistent definition and measures of gentrification across the U.S. To be more specific, this study is designed to answer the question—Do rapid transit lines induce gentrification in MSAs in the U.S.? The study area covers all the 40 MSAs in which new rapid transit station opened between 2000 and 2009. All neighborhoods that are newly served by those newly opened rapid transit stations are included in this study. This study therefore is a population study and not a sample. In addition, this research design address more potential bias summarized in the study of Pandeiro et al. (2019) than the previous empirical examinations of TIG.

3.2 Methodology

3.2.1 Nation-wide study on rapid transit

This chapter conducts a nation-wide examination of the TIG hypothesis under a quasi-experimental research design and using the consistent definition and measure of gentrification. To be more specific, the study area in this chapter includes all the 40 metropolitan areas (MSAs) that have rapid transit stations opened from 2000 through 2009 (details follow in section 3.2.4). The period of 2000 – 2009 is selected, because it allows the comparisons of the same neighborhoods between the two Census years—2000 and 2010, with allowing at least one year of change after the station opened for the examination of TIG hypothesis. As shown in Figure 3, the 40 MSAs are scattered across the contiguous United States. Most (70%) of the MSAs have a population above one million.

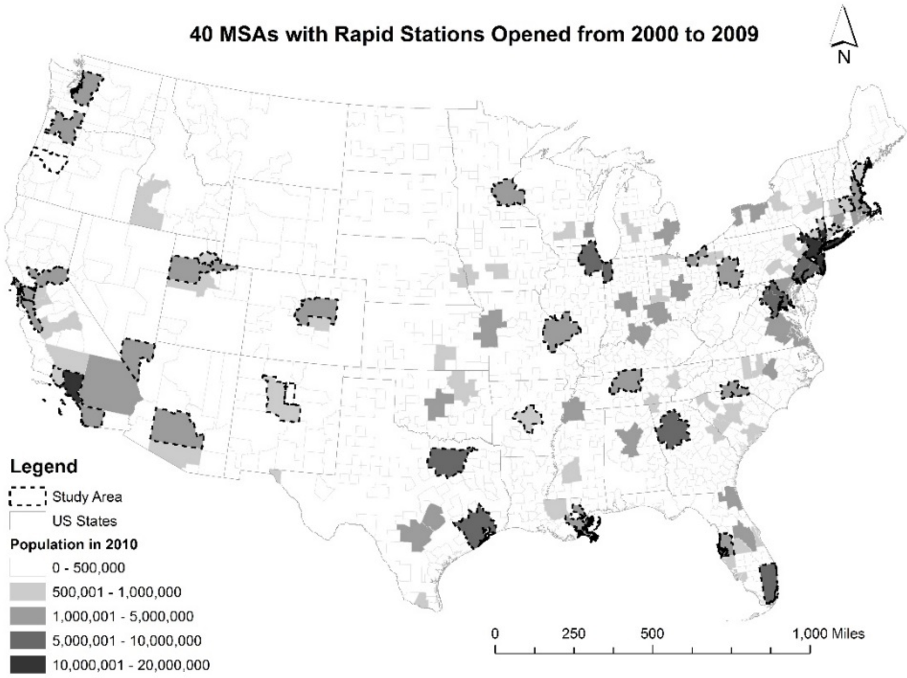

Figure 3 Study Area

In this study, rapid transit is defined to include both rail transit and Bus Rapid Transit (BRT) (Table 3). The definition of rail transit is usually clear and exclusive, including transit modes with the vehicle travel along the fixed rails (e.g., heavy or light rail). BRT, however, is often defined differently by public transit agencies and scholars, and therefore is somewhat ambiguous. Generally speaking, BRT is "a high-quality bus-based transit system that delivers fast, comfortable, and cost-effective services at metro-level capacities." (ITDP, 2020) Some characteristics that distinguish BRT from traditional bus service include exclusive lanes, limited stops or express routes, higher level boarding, traffic light priority, pre-pay systems (i.e., off-board fare collection), and fast and frequent operations. Even though the service of BRT is usually faster, more frequent, and more stable than the traditional bus service, the BRT systems come in many shapes and forms, and they vary in their cost and quality of service (Wright & Hook, 2007; Cervero & Dai, 2014). To distinguish the different qualities of the BRT lines, some studies define "high-end BRT" to describe the BRT with higher quality services and "BRT Lite" to describe the BRT with lower quality services (e.g., Cervero & Dai, 2014). Because the objective of this study is to test whether rapid transit lines (i.e., high-quality transit lines) could induce gentrification in the neighborhoods they served, the high-end BRT is examined specifically for all comparisons, in addition to the all types of BRT systems. The high-end BRT line is defined as the BRT line with exclusive lanes, limited stops/express routes, traffic light priority, and a pre-pay system (i.e., off-board fare collection). There are multiple ways to accommodate the exclusive lanes, but the definition of high-end BRT requires at least one type of exclusive lanes among a subset of exclusive lanes, which includes dedicated busway/tunnel, exclusive highway lands, and exclusive on-street lanes.

Table 3 Definitions of Basic Terms

Term	Definition
Gentrification	The upgrading process and changes that occur in lower-income and/or minority neighborhoods with the influx of more affluent residents, usually disproportionally white, the increases in property values, the renovation of housing, the upscaling of local commercial and retail properties, and potentially, the displacement of current residents.
Transit-Induced Gentrification	The phenomenon that the open of new rapid transit stations could induce gentrification in the neighborhoods that are newly served by those rapid transit stations.
Upgrading	The physical and social improvement of the neighborhoods.
Rapid Transit	"A form of public transportation on a fixed route that includes features that dramatically improve the speed, capacity, reliability, and quality of the service". * In this study, rapid transit is defined to include both rail transit and Bus Rapid Transit.
Rail Transit	Transit modes whose vehicles travel along fixed rails - bars of rolled steel - forming a track. **
Bus Rapid Transit (BRT)	A high-quality bus-based transit system that delivers fast, comfortable, and cost-effective services at metro-level capacities. *** Fixed-route bus systems that operate at least 50 percent of the service on fixed guideway. **
High-end BRT	A term describes the BRT with high quality. It is selected from the BRT and requires the BRT lines must have: 1) exclusive lanes; 2) limited stops/express routes; 3) traffic light priority; and 4) a pre-pay system. There are various types of exclusive lanes of BRT, including: 1) dedicated busway/tunnel; 2) exclusive highway lanes; 3) exclusive on-street lanes; 4) part-time exclusive lanes; 5) no exclusive lanes but heavy intersection bypass lanes; 6) hard shoulders that could be used in congestion; and 7) high-occupancy vehicle (carpool) lanes. The criteria of exclusive lanes that defines the high-end BRT in this study requires the BRT lines must have at least one of the first three types of exclusive lanes (dedicated busway/tunnel, exclusive highway lanes, or exclusive on-street lanes)

Sources:
* BRT Planning Guide: https://brtguide.itdp.org/
** Federal Transit Administration: https://www.transit.dot.gov/ntd/national-transit-database-ntd-glossary

*** The Bus Rapid Transit Standard: https://www.itdp.org/library/standards-and-guides/the-bus-rapid-transit-standard/

Based on these definitions of rapid transit, a total of 763 rail stations opened from 2000 through 2009 in 35 metropolitan areas (MSAs) in the U.S., with the count of rail stations ranging from 2 to 112 across these MSAs (Table 4). During the same period, 237 BRT stations opened in 7 metropolitan areas, with the count of BRT stations ranging from 14 to 60 across the MSAs. Two MSAs had both new rail stations and new BRT stations: Los Angeles, California and Albuquerque, New Mexico. Within the 237 BRT stations opened from 2000 through 2009, only 43 satisfy the definition of high-end BRT stations. All of the high-end BRT stations are stations of the Metro Silver Line in Los Angeles, California, opened in 2009.

Table 4 Count of Rapid Transit Stations Newly Opened from 2000 to 2009

Rapid transit modes	Count of newly opened stations (2000 – 2009)	Count of metropolitan areas (MSAs) where the stations located in
Rail	763	35
BRT	237	7
High-end BRT	43	1

3.2.2 Quasi-experimental design

The opening of a rapid transit station can be viewed as a natural experiment, through which the neighborhoods have new exposure to rapid transit service. This natural experiment resembles the random assignment of the experiment (e.g. Dunning, 2012), although the risk of endogeneity still exists, because the choices of MSAs and the neighborhoods treated with the new rapid transit could be affected by regional and local factors during the planning. Under the setting of the natural experiment, a quasi-experimental design can be applied to examine the Transit-Induced Gentrification (TIG) hypothesis. The neighborhoods that are newly served by the new rapid transit stations are viewed as the treatment (or experimental) group. Rather than selecting a sample set from the population of treated neighborhoods in the U.S. for the hypothesis examination, the entire population (i.e., all rapid-transit-served neighborhoods opened during the study period) is used as the treatment group. This approach avoids the potential bias of non-stochastic sampling for the experiment.

As previous studies indicated, even though this is a quasi-experimental design, if the observations in the control group are "almost identical" to the observations in the treatment group, this design approximates a true experiment with random assignment and may yield the non-biased outcomes of the examination (Dong, 2017; Cao, 2010; Cao et al., 2010). To select the "almost identical" control group, the non-parametric propensity score matching approach is applied based on the neighborhoods' characteristics before the station opened (Ho et al., 2007; Ho et al., 2011). Details will be discussed in Section 3.2.3 Details of the selection of treatment and control groups.

For both the treatment and control groups, pretest-posttest on neighborhood characteristics (i.e., indicators of gentrification) are applied before and after the intervention, which is the opening of the rapid transit stations. To test the TIG hypothesis, statistical tests are conducted between the treatment and control groups for their changes before and after the rapid transit opening.

Overall, this study design satisfies most of the "bias assessment criteria" of a qualified research design of examining the TIG hypothesis developed by Padeiro et al. (2019), and makes this study valid enough to give an unbiased result.

3.2.3 Selection of treatment and control groups

This section states the details of selecting the treatment and control groups for the quasi-experimental design to examine the TIG hypothesis.

First, the TIG hypothesis states that the opening of rapid transit can induce the gentrification in the gentrifiable (i.e. eligible to gentrify) neighborhoods that are newly served by those rapid transit stations. Based on the formulation of TIG hypothesis, the rapid-transit-served area (RTS area) is defined as the area that are accessible by half-mile walk from the rapid transit station. The half-mile walkable buffers are generated based on the street network through ArcGIS online.

Most previous gentrification studies in the U.S. use Census tracts (CT) as the areal unit of analysis. This approach may be partly because of the lack of access to longitudinal data for smaller spatial units. However, a comparison of the typical CT area with the RTS area suggests that CTs may be too large in most cases. To be more specific, CTs, with a median land area of 1.88 mi^2 and a median population size of 3,993 in 2010, are much larger than the RTS buffers, with a median area of 0.35 mi^2 and ranging from 0.01 to 0.95 mi^2. Therefore, CTs that are adjacent to the rapid transit stations in most cases only have a small portion served by the stations (i.e., is within walkable distance). Therefore, in this study, Census block groups (CBGs), the smallest spatial unit with data available for analysis and with a median land area of 0.51 mi^2 and a median population size of 1,240 in 2010, are used as the principal areal unit of analysis. In addition, to explore whether the results of new CBG analyses are different from the results of the traditional CT analyses, the CT analyses are also conducted under the same research design.

The treatment group here is defined as the CBGs that are newly served by the new rapid transit stations opened between 2000 and 2009. This definition requires two criteria of selection: 1) the CBGs need to be served by the rapid transit stations opened between 2000 and 2009; and 2) the CBGs should not be served by the rapid transit stations opened before 2000. Since the boundaries of CBGs and the boundaries of RTS areas are not perfectly overlapped, the definition of "served" in this dissertation is that the CBG is intersected with the RTS area, with the intersected area greater or equal to 10% of the RTS area, or greater or equal to 30% of the CBG. The two criteria of defining "served" here (i.e., 10% and 30%) are selected because jointly, they make sure every station is associated with at least one CBG.

In addition, current scholars debate the interpretations of neighborhood upgrading induced by the opening of transit stations. As discussed in section 3.1, as one among several forms of neighborhood upgrading (Teernstra & Gent, 2012), gentrification usually refers to the neighborhood upgrading in the low-income and/or minority neighborhoods, whereas neighborhood upgrading usually does not require the lower socioeconomic status of the neighborhoods before the upgrading process. Some scholars have argued that the opening of transit stations could also bring upgrading in the neighborhoods that are already "gentrified", in addition to the low-income and/or minority neighborhoods defined by gentrification (e.g., Chapple & Loukaitou-Sideris, 2019). Previous studies usually use the word "gentrifiable" to distinguish the neighborhoods with different potential for gentrification, in other words, the eligibility for gentrification (Hammell and Wyly, 1996; Freeman, 2005; McKinnish, Walsh, & White, 2010). In this study, the CBGs in the treatment group are also divided into gentrifiable and non-gentrifiable CBGs based on their socioeconomic characteristics before the station opened (i.e., in 2000). Three criteria are used to define a gentrifiable CBG: 1) its median household income is within the bottom 40th percentile in the MSA; 2) its median property value is within the bottom 40th percentile in the MSA; and 3) its total population is greater than or equal to 150 (500 for the CT). The first two criteria identify the neighborhoods (i.e., CBGs/CTs) with gentrification potential, and the third criteria makes sure that the neighborhoods have enough residents to be gentrified (i.e., there is a population that may be adversely affected by the process of gentrification). Based on the criteria of gentrifiability, if only gentrifiable treated CBGs show significantly faster upgrading in the indicators of gentrification than their corresponding control groups, the opening of rapid transit stations would only induce gentrification. In contrast, if both the gentrifiable and non-gentrifiable treated CBGs show significantly faster upgrading in the indicators of gentrification than the control group, the opening of rapid transit stations would induce gentrification in the gentrifiable neighborhoods, and in the meantime, the new stations would also induce the upgrading in non-gentrifiable neighborhoods.

The CBGs in the control groups are selected by nonparametric propensity score matching, using the *MatchIt* package in the statistical software *R* (Ho et al., 2007 & 2011). *Matchit* provides several matching methods. The *Optimal Matching* is selected, with the ratio set as three, because this method allows pairing a control group of three (i.e., the ratio) best matched (i.e., most similar) CBGs/CTs for each CBG/CT in the treatment group. This approach allows examination of the TIG hypothesis for different rapid transit modes and for all treated, gentrifiable treated, and non-gentrifiable treated groups separately. Here the CBGs/CTs of the control group are selected from the pool of CBGs/CTs in the same MSA with each CBG/CT in the treatment group; none is served by rapid transit stations until 2010.

The propensity score matching factors include 16 indicators covering the demographic, neighborhood income, housing, and locational characteristics at the year of the pretest—2000 (Table 5) to make sure the CBGs in the control group are "almost identical" to the CBGs in the treatment group before the intervention. In addition, the study period (2000 – 2010) coincides with the Great Recession during the late 2000s. Different from the previous recessions such as the one of 1981 – 1982, the Great Recession caused the shock in the stock market, the housing market, and the labor market simultaneously (Hurd & Rohwedder, 2010). The large upheavals in the housing market could occur unevenly across neighborhoods, and this unevenness would challenge our assumption that the selected control group is "almost identical" to the treatment group, raising the risk of bias of the examination, especially of the housing indicators of gentrification. Therefore, controlling the impact of the Great Recession when selecting the CBGs of the control group is necessary and helps to reduce the risk of bias. Two indicators are used to indicate the impact of the Great Recession on the CBGs: 1) changes of unemployment rate, and 2) changes of affordable mortgage rate. Details of the indicators are shown in Table 5.

Table 5 Factors for Propensity Score Matching

Factors	***Description***
Demographic	
Minority	Percentage of black and Hispanic population in 2000
Age	Percentage of young people aged 25–39 in 2000
Children	Percentage of families with children under 18 years old in 2000
Education	Percentage of adults (25+) with at least bachelor's degree (college-educated) in 2000
Neighborhood Income	
Income	Median household income in 2000
Housing	
Unit density	The density of housing units
Tenure	Percentage of rental units in 2000
House size	Percentage of small-sized units with 0–2 bedrooms in 2000
Home value	Median property value in 2000
Rent	Median contract rent in 2000
Unit structure	Percentage of detached single-family homes in 2000
Locational	
Distance to freeway	Distance to the nearest exist of freeway (in miles)
Distance to CBD	Distance to city center (in miles)
Accessibility	Accessible jobs within 30 minutes by auto in 2015 (due to data availability)
Recession	
Change of unemployment rate	Unemployment rate change between 2008 and 2011
Change of affordable mortgage rate	Percentage change of units with mortgage-to-income ratio > 30% between 2008 and 2010

The pretest and posttest comparisons are applied between the treatment and control groups by the Paired T-tests on their respective rates of change for each of the nine indicators of gentrification. Each CBG/CT in the treatment group is compared with the average of their three corresponding CBGs/CTs in the control group. The indicators of gentrification cover changes of housing and demographic characteristics, as well as neighborhood income of the CBGs/CTs. The details of indicators of gentrification are listed in Table 6. Among them, five indicators are viewed as the core indicators of gentrification, including two housing indicators—median property value and median rent, two demographic indicators—share of residents with college education and share of residents in professional occupations, and the neighborhood income indicator—median household income, because these five indicators together indicate the major changes suggested by the definition of gentrification, such as higher housing cost and more affluent residents with higher incomes or higher income potential. In addition, the affluent residents are usually disproportionately white, and because of housing segregation associated with structural racism in the U.S., the lower-income residents likely to be adversely affected likely to be disproportionately minority (e.g., black and Hispanic). Therefore, the share of white residents is also included as one of the indicators of gentrification. However, an increase in the share of white residents alone without other changes does not demonstrate gentrification. Together with the core changes of gentrification, increases in the share of white residents can show people of color are more vulnerable to gentrification. In addition to the test of indicators for their rates of change between 2000 and 2010, the pretest and posttest comparisons also include the test of indicators for their longitudinal rate of change between 2000 and 2016 to check the validation of the short-term examination results, which could have risk of bias due to the impacts of the Great Recession.

Table 6 Indicators of Gentrification

Factors	**Indicators**
Housing	Median property value Median rent Proportion of owner-occupied dwellings Total occupied housing
Demographic	Total population Proportion of residents with college education Proportion of residents in professional occupations Proportion of white residents
Neighborhood income	Median household income

3.2.4 Data sources

The study requires both spatial data and socio-economic data. The spatial data about rail stations and BRT stations are extracted from the Homeland Infrastructure Foundation-level Data (HIFID) and Official General Transit Feeds Specification (GTFS) data, respectively. The opening year of those stations are manually collected from the Wikipedia or their official websites. The spatial boundaries of Census block groups (CBGs) and Census tracts (CTs) are based on the definition in 2010 from the NHGIS of Minnesota Population Center (MPC).

The socio-economic data come from the 2000 Census, 2010 Census, and the 5-year American Community Surveys (ACS) (Table 7). Due to the changes of geographic boundaries between the 2000 Census and 2010 Census, the comparisons between 2000 and 2010/2016 require estimates using 2010 boundaries for the variables from the 2000 Census. In this study, I obtain the estimates of 2000 Census in 2010 boundaries for Census block groups (CBGs) and Census tracts (CTs) using the geographic crosswalks from 2000 blocks to 2010 blocks offered by the National Historical GIS (NHGIS) of the Minnesota Population Center (MPC) (Manson et al., 2019). These geographic crosswalk files use the interpolation weights derived from advanced models, considering the distribution of population and housing. Through the block-level estimates, the CBGs and CTs estimates are generally accurate. Due to the large data size, the supercomputer from U-Spatial of University of Minnesota is used for the estimation. For the socio-economic data in years other than 2000 and 2010, the 5-year American Community Survey (ACS) data are used, with assuming the 5-year ACS data estimate the levels of the variables at the median year. For example, I assume the measures of the variables in 2016 represent the period 2014 – 2018. Together with the Census data in 2000 and 2010, a longitudinal dataset is created covering the years of 2000, 2008 – 2016 for the geographic levels of CBG and CT in the United States.

Table 7 Summary of the Data Source

Data		Data Source
Spatial data	Rail transit stations	Homeland Infrastructure Foundation-level Data (HIFID)
	BRT stations	Official General Transit Feeds Specification (GTFS)
	Year station opened	Manually collected from the Wikipedia and official websites
	Spatial boundaries	2010 definition (NHGIS standards)
Socio-economic data		Census in 2000 & 2010, 5-year ACS data (2011 – 2018) All downloaded from NHGIS of MPC at UMN, manually matched through blocks using the crosswalk files offered by NHGIS for 2000.

3.3 Propensity Score Matching Results

As presented in Table 8, the non-parametric propensity score matching of both CBG and CT analyses selects similar control groups for the corresponding treatment group. Both the means and standard deviations between the treatment group and control group are similar for all factors. The standard deviations of the matching factors for both the treatment groups and the control groups are large, suggesting high variation within each group (Table 8). To be more specific, some matching factors show extra high variation among the CBGs/CTs with their standard deviation even larger than their means. The factors with standard deviations greater than means include the percentage of black residents, the percentage of Hispanic residents, unit density, distance to free way, and the change of unemployment rate. For all other matching factors, their standard deviations are all above or at least about 30% of their means. This high variation could result from the differences among the 40 different MSAs, or from the different CBG/CT characteristics in the same MSA.

Differences between CBGs and CTs. The means and standard deviations of treatment group are also similar between CBGs and CTs for many matching factors, but the comparisons of the means and standard deviations between the CBGs and CTs confirm that important differences exist and could affect the TIG analysis. For example, the median household income, median property value, and median rent are slightly higher with slightly smaller deviations in the treated CTs than the treated CBGs, indicating the neighborhoods that are a little farther away from the new rapid transit stations are neighborhoods with slightly higher-income than the neighborhoods that are adjacent to the stations. The mean unit density of the treated CTs is only about 72% of the mean of treated CBGs, indicating a higher unit density in the neighborhoods that are adjacent to the newly opened transit stations. It needs to be noted that the standard deviations of unit density for both treated CBGs and CTs are larger than their means, indicating a large variation among the CBGs in treatment group for unit density. In addition, the change of affordable mortgage rate are a little higher in the treated CTs than the treated CBGs, indicating the neighborhoods that are a little farther away from the stations had greater changes of affordable mortgage rate during the Great Recession than the neighborhoods that are adjacent to the stations. This could result from the slightly higher property values in the neighborhoods that are a little farther away from the stations, which means the higher property cost will make residents burdened more from the loss or change of jobs during the Great Recession.

Table 8 Results Summary of Non-Parametric Propensity Score Matching

Variables	Census Block Group				Census Tracts			
	Treatment		Control		Treatment		Control	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Demographic								
% of Black	16.90%	25.60%	15.30%	26.30%	15.65%	24.47%	15.26%	26.04%
% of Hispanic	25.30%	26.70%	25.10%	27.30%	24.75%	25.79%	23.95%	25.84%
% of Young	26.70%	8.60%	25.80%	7.90%	26.32%	7.81%	25.30%	6.95%
% of Family with Children	89.00%	33.20%	90.20%	31.70%	90.10%	29.72%	92.83%	28.72%
% of College-educated	25.60%	19.40%	25.40%	18.90%	26.55%	18.53%	25.83%	17.95%
Neighborhood income								
Median Household Income	39,141	18,744	41,906	19,875	41,321	18,394	43,698	18,962
Housing								
Unit density (/mi^2)	5,019	7,344	4,791	6,636	3,629	4,792	3,606	4,148
% of Rent units	57.40%	27.60%	51.30%	28.10%	54.67%	25.39%	48.75%	25.90%
% of Small size units	65.00%	24.30%	59.90%	25.30%	62.82%	22.35%	57.85%	24.19%
Median Property value	160,454	99,509	159,900	100,228	164,303	93,840	164,822	94,464
Median Rent	611	239	630	249	620	222	632	230
% of Detached Housing	37.30%	30.60%	43.30%	32.10%	40.61%	27.89%	46.31%	29.46%
Locational								
Distance to freeway	1.206	1.462	1.327	1.806	1.284	1.417	1.555	2.410
Distance to CBD	6.735	6.456	7.434	6.696	7.180	6.740	8.363	7.507
Accessibility	1,708,287	1,335,483	1,675,657	1,322,939	1,602,813	1,271,459	1,571,881	1,259,573
Recession								
Change of unemployment rate	1.70%	7.90%	1.70%	6.90%	1.70%	4.45%	1.86%	4.39%
Change of affordable mortgage rate	113.50%	60.20%	111.60%	57.80%	121.54%	44.09%	126.47%	49.20%

3.4 Neighborhood Changes in Treatment Group

Before examining the hypothesis of Transit-Induced Gentrification (TIG), the changes in neighborhoods are first explored in terms of the percentages of CBGs/CTs that experienced increase in each indicator of gentrification between 2000 and 2010.

Among the treated CBGs/CTs, near, but less than half are gentrifiable, for all treated, rail-served, and BRT-served CBGs/CTs. More than half of the CBGs/CTs served by high-end BRT are gentrifiable. To be more specific, as shown in Table 9, there are in total 1513 treated CBGs and 692 (45.7%) of them are gentrifiable. Among all treated CBGs, 1208 are served by rail with 555 (45.9%) gentrifiable, 348 are served by BRT with 154 (44.3%) gentrifiable, and among the 348 served by BRT, 89 are served by high-end BRT with 57 (64.0%) gentrifiable. In contrast, there are in total 853 treated CTs and 393 (46.1%) of them are gentrifiable. Among all treated CTs, 698 are served by rail with 332 (47.6%) gentrifiable, 182 are served by BRT with 77 (42.3%) gentrifiable, and among the 182 served by BRT, 50 are served by high-end BRT with 28 (56.0%) gentrifiable. There are 43 CBGs and 27 CTs served both by rail and BRT.

The changes in neighborhoods between 2000 and 2010 show generally similar patterns between all treated and gentrifiable treated neighborhoods, across different transit modes, and between analyses of CBGs and of CTs (Table 9), but the patterns are complex and vary in some details. In addition, the percentages of CBGs/CTs that experienced increases are different across the nine indicators of gentrification.

Percentages of Census Block Groups with Increases in Indicators of Gentrification

For all treated group, the four indicators with the highest percentages of CBGs that experienced increase between 2000 and 2010 are median property value (90.4%), median rent (76.8%), proportion of residents with college education (70.5%), and proportion of residents in professional occupations (59.1%), all of which are among the five core indicators of gentrification (Table 9). In addition, 50.9% of the CBGs experienced an increase in the other core indicator—median household income. The percentages of CBGs that experienced increases in total occupied housing and total population are 54.7% and 54%, respectively; whereas the percentages are lower for proportion of owner-occupied housing (42.2%) and proportion of white residents (41.8%).

The percentages of gentrifiable treated CBGs are slightly higher than the percentages of all treated CBGs for three indicators: median property value (91.2%), median rent (78%), and proportion of white residents (49.9%). The other six indicators have slightly lower percentages of CBGs that experienced increases between 2000 and 2010 in the gentrifiable treated subgroup than the all treated group. The percentage gaps between the gentrifiable treated and all treated are limited to 3%, except proportion of white residents (8.1% higher for gentrifiable treated) and total population (6.3% lower for gentrifiable treated).

With regard to increases in indicators, the percentages in both all treated and gentrifiable treated CBGs served by rail are generally comparable with the corresponding percentages of CBGs served by BRT for most of the indicators of gentrification. All the five core indicators of gentrification have higher percentages, whereas all the other four indicators have lower percentages in rail-served CBGs than BRT-served CBGs for both all treated groups and gentrifiable treated subgroups, and the gaps are larger for gentrifiable subgroups than for all treated groups. Among the BRT-served CBGs, however, higher percentages of the high-end BRT-served CBGs than the rail-served CBGs have increases in most of the indicators except total housing units, and proportions of residents with college education and of residents in professional occupations (for all treated groups only). These results show that generally speaking, the percentages of CBGs that experienced increases with respect to the core indicators of gentrification are higher in rail-served CBGs than in BRT-served CBGs, but among the BRT-served CBGs, high-end BRT-served CBGs have higher percentages than rail-served CBGs with respect to almost all the indicators.

Table 9 Percentages of Census Block Groups and Census Tracts Experiencing Upgrading between 2000 and 2010

Measure (% of increase) 2000 – 2010	All				Rail			
	Census Block Groups		Census Tracts		Census Block Groups		Census Tracts	
	All Treated	Gentrifiable Treated	All Treated	Gentrifiable Treated	All Treated	Gentrifiable Treated	All Treated	Gentrifiable Treated
Counts	1513	692	853	393	1208	555	698	332
Housing								
Median property value	90.4	91.2	93.1	93.9	90.3	91.5	93.1	94.0
Median rent	76.8	78.0	78.8	83.2	76.8	78.4	79.1	84.0
Proportion of owner-occupied dwellings	42.2	40.3	38.9	33.6	41.2	38.2	37.7	30.1
Total occupied housing	54.7	52.0	63.0	60.8	53.5	50.8	62.6	59.6
Demographic								
Total population	54.0	47.7	59.7	52.9	52.2	45.9	57.6	50.3
Proportion of residents with college education	70.5	68.4	77.0	73.5	72.8	70.6	78.7	73.5
Proportion of residents in professional occupations	59.1	57.8	63.2	60.8	61.4	59.8	65.0	62.0
Proportion of white residents	41.8	49.9	37.7	47.1	39.7	47.0	36.1	44.9
Neighborhood income								
Median household income	50.9	47.8	46.9	43.8	52.1	48.8	48.0	44.9

Table 9 Percentages of Census Block Groups and Census Tracts Experiencing Upgrading between 2000 and 2010 (Continued)

Measure (% of increase) 2000 – 2010	**BRT**				**High-End BRT**			
	Census Block Groups		**Census Tracts**		**Census Block Groups**		**Census Tracts**	
	All Treated	Gentrifiable Treated	All Treated	Gentrifiable Treated	All Treated	Gentrifiable Treated	All Treated	Gentrifiable Treated
Counts	348	154	182	77	89	57	50	28
Housing								
Median property value	89.9	89.6	91.8	93.5	95.5	98.2	92.0	96.4
Median rent	77.6	75.3	78.6	80.5	87.6	89.5	94.0	100.0
Proportion of owner-occupied dwellings	45.1	50.0	44.0	49.4	48.3	50.9	54.0	42.9
Total occupied housing	57.8	55.8	63.7	67.5	50.6	54.4	50.0	67.9
Demographic								
Total population	60.6	55.2	67.6	66.2	56.2	56.1	62.0	67.9
Proportion of residents with college education	64.1	61.7	72.5	76.6	64.0	64.9	78.0	85.7
Proportion of residents in professional occupations	52.0	51.3	55.5	53.2	48.3	52.6	56.0	57.1
Proportion of white residents	50.0	59.1	45.1	55.8	66.3	77.2	60.0	71.4
Neighborhood income								
Median household income	47.1	44.2	41.2	37.7	58.4	57.9	62.0	64.3

Percentages of Census Tracts with Increases in Indicators of Gentrification

Similar to the CBG analysis, for all treated group, the four indicators with the highest percentages of CTs that experienced increase between 2000 and 2010 are still the median property value (93.1%), median rent (78.8%), proportion of residents with college education (77%), and proportion of residents in professional occupations (63.2%), all of which are among the five core indicators (Table 9). In addition, 46.9% of the CBGs experienced increase in the other core indicator—median household income. The percentages of CBGs that experienced increase in total occupied housing and total population are 63% and 59.7%, respectively; whereas the percentages are lower for proportion of owner-occupied housing (38.9%) and proportion of white residents (37.7%).

The percentages of gentrifiable treated CTs are also higher than the percentages of all treated CTs for the three indicators: median property value (93.9%), median rent (83.2%), and proportion of white residents (47.1%). The other six indicators have lower percentages of CTs that experienced increase between 2000 and 2010 in the gentrifiable treated subgroup than the all treated group. The percentage gaps between the gentrifiable treated and all treated CTs are only small for median property value. All the other eight indicators for the CT analysis have their percentage gaps between the gentrifiable treated and all treated CTs larger than the gaps for the CBG analysis, but most of these gaps are still smaller than 5%, except proportion of white residents (9.4% higher for gentrifiable treated) and total population (6.8% lower for gentrifiable treated).

Also similar to the CBG analysis, the percentages in both all treated and gentrifiable treated CBGs served by rail are generally comparable with the corresponding percentages of CBGs served by BRT for most of the indicators of gentrification. All the five core indicators of gentrification have higher percentages in rail-served CTs than BRT-served CTs, except the proportion of residents with college education in the gentrifiable treat group, which has lower percentage in rail-served CTs than BRT-served CTs. All the other four indicators have lower percentages in rail-served CTs than BRT-served CTs for both all treated groups and gentrifiable treated subgroups, and the gaps are larger for gentrifiable subgroups than for all treated groups. However, the high-end BRT-served CTs, as a subgroup of the BRT-served CTs, do not follow the patterns in the comparison with rail-served CTs. Of all treated groups, five indicators have higher percentages in high-end BRT-served CTs than rail-served CTs: median rent, proportion of owner-occupied dwellings, total population, proportion of white residents, and median household income. In contrast, of gentrifiable treated subgroups, all the indicators, except the proportion of residents in professional occupations, have higher percentages in high-end BRT-served CTs than rail-served CTs. To summarize, the results of CT analysis are consistent with the CBG analysis, showing that the percentages of CBGs that experienced increases with respect to the core indicators of gentrification are higher in rail-served CBGs than in BRT-served CBGs. However, among the BRT-served CBGs, the high-end BRT-served CBGs show different patterns when comparing with the rail-served CTs, with generally higher or similar percentages than rail-served CTs, especially for the gentrifiable treated groups.

<u>Comparisons between Census Block Groups and Census Tracts</u>

The analyses of CBGs and of CTs give similar patterns for the neighborhood changes, in terms of the percentages of CBGs/CTs that experienced increase in each of the nine indicators of gentrification. Some differences, however, exist between the results of CBG analysis and of CT analysis. For both the comparisons of all treated groups and gentrifiable treated groups without distinguishing different transit modes, the CBG analysis only gives higher percentages than the CT analysis in three indicators of gentrification: proportion of owner-occupied dwellings, proportion of white residents, and median household income, and gives lower percentages in all the other six indicators. The gaps are the same or larger between gentrifiable treated groups than between all treated groups for housing indicators, but are smaller for demographic indicators, and are the same for neighborhood income indicator.

For both rail-served and BRT-served areas, the comparisons between the percentages of CBGs and of CTs follow the patterns of similarities and differences of the comparisons without distinguishing different transit modes, with the same three indicators showing higher percentages in the CBG analysis than in the CT analysis: proportion of owner-occupied dwellings, proportion of white residents, and median household income. However, the differences in percentages between the CBG analysis and CT analysis have different patterns between the two transit modes. For rail-served areas, the gaps are larger between gentrifiable treated groups than between all treated groups for only two indicators: median rent and proportion of owner-occupied dwellings. In contrast, for BRT-served areas, the gaps are larger between gentrifiable treated groups than between all treated groups for six indicators: median property, median rent, total housing units, total population, proportion of residents with college education, and median household income. For high-end BRT-served areas, which is a subgroup of the BRT-served areas, the patterns are more complex. The CBG analysis gives higher percentages than the CT analysis in four indicators: median property value (for both all treated and gentrifiable treated), proportion of owner-occupied dwellings (for gentrifiable treated only), total housing (for all treated only, and the difference is only 0.6%), and proportion of white residents (for both all treated and gentrifiable treated).

The comparisons show that complex differences exist between the analyses of CBGs and of CTs in terms of the increases of indicators of gentrification. These complex differences suggest that the CBGs, which could give more precise definition of transit-served areas as the areal unit of analysis than CTs, could also give more effective analyses of neighborhood changes and TIG than the CTs.

Comparisons across Indicators of Gentrification

The nine indicators of gentrification perform differently in indicating the changes of neighborhoods, and the patterns of differences among the indicators are generally consistent across the treatment group and its subgroups of gentrifiable treated and of different transit modes (Table 9). To be more specific, the percentages of CBGs/CTs that experienced increases in each indicator vary across the nine indicators of gentrification. For example, the percentages of CBGs/CTs that experienced increase of median property value are above or about 90% for all treatment group and subgroups, of median rent are about 80% in rail-served areas and BRT-served areas, and about 85 – 100% in high-end BRT served areas. In addition, above 70% CBGs/CTs in rail-served areas, and about 60 – 65% CBGs and about 70% - 85% CTs in BRT- and high-end BRT-served areas experienced increase in proportion of residents with college education. Different from those high percentages, the percentages of CBGs/CTs that experienced increase in proportion of white residents are only about 35 – 45% in rail-served areas, with a slightly higher percentage in gentrified rail-served areas. However, the percentages of high-end BRT-served CBGs/CTs can reach to about 60 – 75% that experienced increase in proportion of white residents. Meanwhile, the percentages of CBGs/CTs that experienced increase are about 50 – 65% for total occupied housing in all transit-served areas, for percentage of residents in professional occupations in rail-served areas, and for population growth in BRT- and high-end BRT-served areas. The percentages of CBGs/CTs that experienced increase are about 30 – 50% for proportion of owner-occupied dwellings in all transit-served areas, and for median household income in BRT-served areas. For all other indicators of gentrification, there are about half of the CBGs/CTs that experienced increase.

These unbalanced percentages across different indicators suggest that the changes of neighborhoods may not be consistent and simultaneous across the housing market, demographic characteristics, and neighborhood income. Even for the housing market, for example, the submarkets of sale and rental could also be different. Those difference suggest us to look at the details of indicators of gentrification separately, and some details could be overlooked if synthesize the indicators.

3.5 An Examination of the Transit-Induced Gentrification Hypothesis

This section summarizes statistical tests of the hypothesis of Transit-Induced Gentrification (TIG). First, the results of means tests (Paired T-tests) on each indicator of gentrification between the treatment group and the corresponding control group are presented to examine the neighborhood upgrading induced by new rapid transit stations (i.e., Transit-Induced Upgrading (TIU)) in terms of the indicators of gentrification. The comparisons (i.e., Paired T-tests) between treatment and control groups are also conducted for the gentrifiable and non-gentrifiable subgroups. The TIU in the gentrifiable subgroups can be interpreted as TIG, whereas the TIU in the non-gentrifiable subgroups cannot.

Hypothesis. The null hypothesis (H_0) for each indicator of gentrification is that the treatment groups have the same rate of change or a slower increase or faster decrease in rate of changes than their corresponding control groups between 2000 and 2010. The alternative hypothesis (H_1) is otherwise (i.e. the rate of increase in the treatment group is significantly greater or the rate of decrease in the treatment group is significantly lower[2]). This is a one-tailed (i.e., upper-tailed) test.

Expectations. If the TIG hypothesis (i.e., the alternative hypothesis) were true, then, for each indicator of gentrification, the treatment group would have significantly faster increases or slower decreases than the corresponding control group. This means the treatment group has a significantly higher rate of change (pretest-posttest) of each indicator of gentrification than the control group (i.e., the differences between the treatment and control groups are significantly positive). In addition, since gentrification, by definition, would be more likely to happen in the

[2] Here as a nation-wide summative study, this study uses a broader definition of gentrification, without excluding the cases when treatment group have a slower decrease than the control group. Some specific causes such as the hurricanes and the Great Recession could cause the overall downgrading of the MSA. Future analyses will include an assessment of the effects of analyzes slower decreases in change as indicators of gentrification.

gentrifiable (i.e., eligible to gentrify) neighborhoods, the expectations of the results of means tests would be that the alternative hypothesis is only true for gentrifiable CBGs/CTs. In contrast, if the means tests show that the alternative hypothesis is both true for gentrifiable and non-gentrifiable CBGs/CTs, then the transit would not only induce gentrification in gentrifiable neighborhoods (TIG), but would also induce the more general neighborhood upgrading (TIU). The expectation of TIG hypothesis is that transit would be more likely to induce gentrification in gentrifiable neighborhoods, but less likely to induce general neighborhood upgrading in non-gentrifiable neighborhoods.

Results.

Table 10 and Table 11 present the results of analyses for short- and long-term analyses, respectively. There are in total 24 sets of examinations of the TIG hypothesis, and each set includes the examination of nine indicators of gentrification. These 24 sets include four levels of analyses which may be viewed as a type of hierarchy: 1) short-term and long-term analyses; 2) analyses of CBGs and CTs; 3) analysis of all rapid transit as a whole, and of three different transit modes—rail, BRT (i.e., BRT as a whole, including high-end BRT), and high-end BRT—separately; and 4) analysis of all treated neighborhoods as a whole, and of gentrifiable and non-gentrifiable treated neighborhoods separately. These four levels are followed for the presentation of results. The numbers in Table 10 and Table 11 are the mean differences between the rate of change of each CBG/CT in the treatment group and the mean rate of change of the three corresponding CBGs/CTs in the control groups for each indicator of gentrification and under each set of examination. A positive number means the treatment group has a faster increase (or slower decrease) of the indicator than the corresponding control group, whereas the negative number means the treatment group has a slower increase (or faster decrease) than the corresponding control group. A larger number suggests a larger gap in the rates of change between the treatment and control groups with regard to an indicator. The stars after the numbers indicate the level of significance of differences in rates of change between the treatment and control (i.e., significance level of the one-tail Paired T-tests).

Table 10 Paired T-tests Results of Hypotheses of Transit-Induced Gentrification and of Transit-Induced Upgrading (2000 - 2010)

Paired T-tests on Hypothesis Treatment > Control	**All**			**Rail**		
	All Treated	**Gentrifiable Treated**	**Non-gentrifiable treated**	**All Treated**	**Gentrifiable Treated**	**Non-gentrifiable treated**
Census Block Groups (2000 - 2010)						
Counts of Census block groups	1513	692	821	1208	555	653
Indicators of Gentrification						
Housing						
Median property value	**0.065** ** (0.048)	**0.171** *** (0.007)	-0.028 (0.761)	**0.050** * (0.095)	**0.135** ** (0.012)	-0.025 (0.699)
Median rent	-2.411 (0.838)	-0.004 (0.608)	-4.540 (0.838)	-3.032 (0.838)	0.003 (0.425)	-5.759 (0.838)
Proportion of owner-occupied dwellings	0.608 (0.127)	-0.018 (0.559)	1.142 (0.123)	0.753 (0.130)	-0.038 (0.601)	1.434 (0.123)
Total occupied housing	0.664 (0.238)	-0.818 (0.909)	1.914 (0.122)	1.095 (0.172)	-0.716 (0.838)	**2.635** * (0.100)
Demographic						
Total population	1.150 (0.209)	-0.988 (0.917)	2.951 (0.123)	1.710 (0.166)	-0.909 (0.859)	3.936 (0.109)
Proportion of residents with college education	0.299 (0.104)	**0.762** * (0.071)	-0.089 (0.952)	**0.399** * (0.090)	**0.936** * (0.073)	-0.057 (0.815)
Proportion of residents in professional occupations	0.004 (0.461)	**0.089** ** (0.014)	-0.069 (0.862)	0.020 (0.331)	**0.127** *** (0.002)	-0.071 (0.817)
Proportion of white residents	0.033 (0.257)	**0.167** * (0.058)	-0.081 (0.999)	0.045 (0.237)	**0.197** * (0.068)	-0.085 (0.997)
Neighborhood income						
Median household income	**0.034** ** (0.013)	0.001 (0.485)	**0.061** *** (0.002)	**0.053** *** (0.001)	**0.034** * (0.090)	**0.070** *** (0.002)

Note: 1) The table reports the differences of the rates of change (pretest-posttest) between the treatment and control groups (treatment minus control) and the p-value of the one-tail Paired T-tests of the differences between the treatment and control groups. 2) * p-value < 0.1, ** p-value < 0.05, *** p-value <0.01.

Table 10 Paired T-tests Results of Hypotheses of Transit-Induced Gentrification and of Transit-Induced Upgrading (2000 - 2010) (Continued)

Paired T-tests on Hypothesis Treatment > Control	**BRT**			**High-end BRT**		
	All Treated	**Gentrifiable Treated**	**Non-gentrifiable treated**	**All Treated**	**Gentrifiable Treated**	**Non-gentrifiable treated**
Census Block Groups (2000 - 2010)						
Counts of Census block groups	348	154	194	89	57	32
Indicators of Gentrification						
Housing						
Median property value	0.130 (0.129)	**0.326** * (0.084)	-0.047 (0.862)	0.173 (0.328)	0.268 (0.321)	-0.021 (0.583)
Median rent	0.007 (0.399)	-0.043 (0.941)	0.047 (0.135)	0.007 (0.439)	-0.030 (0.755)	0.071 (0.221)
Proportion of owner-occupied dwellings	0.089 (0.158)	**0.168** * (0.076)	0.026 (0.422)	0.142 (0.255)	0.360 (0.125)	-0.258 (0.886)
Total occupied housing	-0.796 (0.925)	-1.110 (0.890)	-0.547 (0.787)	0.441 (0.142)	-0.024 (0.712)	1.270 (0.136)
Demographic						
Total population	-0.801 (0.914)	-1.172 (0.874)	-0.506 (0.775)	**0.564** * (0.078)	0.015 (0.374)	**1.542** * (0.082)
Proportion of residents with college education	0.006 (0.476)	0.145 (0.216)	-0.103 (0.8601)	**0.427** * (0.066)	**0.858** ** (0.015)	-0.327 (0.826)
Proportion of residents in professional occupations	-0.049 (0.832)	-0.023 (0.591)	-0.069 (0.941)	0.026 (0.394)	0.064 (0.318)	-0.040 (0.620)
Proportion of white residents	-0.009 (0.681)	0.047 (0.115)	-0.054 (0.999)	**0.101** ** (0.011)	**0.202** *** (0.001)	-0.0785 (0.976)
Neighborhood income						
Median household income	-0.042 (0.955)	-0.119 (1.000)	0.018 (0.301)	-0.074 (0.970)	-0.085 (0.945)	-0.053 (0.831)

Note: 1) The table reports the differences of the rates of change (pretest-posttest) between the treatment and control groups (treatment minus control) and the p-value of the one-tail Paired T-tests of the differences between the treatment and control groups. 2) * p-value < 0.1, ** p-value < 0.05, *** p-value <0.01.

Table 10 Paired T-tests Results of Hypotheses of Transit-Induced Gentrification and of Transit-Induced Upgrading (2000 - 2010) (Continued)

Paired T-tests on Hypothesis Treatment > Control	All			Rail		
	All Treated	**Gentrifiable Treated**	**Non-gentrifiable treated**	**All Treated**	**Gentrifiable Treated**	**Non-gentrifiable treated**
Census Tracts (2000 - 2010)						
Counts of Census tracts	853	393	460	698	332	366
Indicators of Gentrification						
Housing						
Median property value	**0.055** * (0.067)	**0.129** *** (0.002)	-0.010 (0.571)	**0.062** * (0.079)	**0.118** *** (0.009)	0.010 (0.444)
Median rent	0.002 (0.429)	-0.002 (0.559)	0.006 (0.391)	0.012 (0.216)	0.010 (0.242)	0.015 (0.297)
Proportion of owner-occupied dwellings	0.029 (0.261)	-0.017 (0.732)	0.069 (0.197)	0.032 (0.282)	-0.032 (0.850)	0.091 (0.186)
Total occupied housing	2.389 (0.177)	-0.198 (0.991)	4.599 (0.168)	2.925 (0.177)	-0.202 (0.981)	5.762 (0.169)
Demographic						
Total population	3.878 (0.166)	-0.263 (0.993)	7.417 (0.159)	4.747 (0.166)	-0.282 (0.988)	9.308 (0.159)
Proportion of residents with college education	0.026 (0.243)	0.040 (0.254)	0.015 (0.380)	0.045 (0.160)	0.061 (0.190)	0.030 (0.303)
Proportion of residents in professional occupations	**0.037** ** (0.021)	**0.068** ** (0.015)	0.011 (0.299)	**0.049** *** (0.008)	**0.095** *** (0.003)	0.007 (0.372)
Proportion of white residents	-0.009 (0.652)	**0.073** ** (0.048)	-0.079 (1.000)	-0.009 (0.624)	**0.073** * (0.076)	-0.083 (1.000)
Neighborhood income						
Median household income	**0.019** * (0.067)	-0.011 (0.773)	**0.044** ** (0.014)	**0.027** ** (0.030)	0.002 (0.452)	**0.050** ** (0.016)

Note: 1) The table reports the differences of the rates of change (pretest-posttest) between the treatment and control groups (treatment minus control) and the p-value of the one-tail Paired T-tests of the differences between the treatment and control groups. 2) * p-value < 0.1, ** p-value < 0.05, *** p-value <0.01.

Table 10 Paired T-tests Results of Hypotheses of Transit-Induced Gentrification and of Transit-Induced Upgrading (2000 - 2010) (Continued)

Paired T-tests on Hypothesis Treatment > Control	**BRT**			**High-end BRT**		
	All Treated	**Gentrifiable Treated**	**Non-gentrifiable treated**	**All Treated**	**Gentrifiable Treated**	**Non-gentrifiable treated**
Census Tracts (2000 - 2010)						
Counts of Census tracts	182	77	105	50	28	22
Indicators of Gentrification						
Housing						
Median property value	0.002 (0.484)	**0.192** *** (0.001)	-0.142 (0.987)	-0.117 (0.823)	0.073 (0.163)	-0.401 (0.913)
Median rent	-0.023 (0.904)	-0.059 (0.996)	0.003 (0.459)	0.005 (0.451)	-0.040 (0.849)	0.060 (0.226)
Proportion of owner-occupied dwellings	0.017 (0.273)	**0.064** * (0.100)	-0.017 (0.698)	-0.039 (0.727)	0.020 (0.405)	0.069 (0.868)
Total occupied housing	-0.038 (0.709)	-0.139 (0.935)	0.037 (0.353)	-0.054 (0.830)	0.019 (0.277)	-0.146 (0.883)
Demographic						
Total population	0.019 (0.407)	-0.138 (0.931)	0.134 (0.137)	0.210 (0.159)	0.024 (0.209)	0.447 (0.178)
Proportion of residents with college education	-0.015 (0.578)	-0.077 (0.715)	0.030 (0.367)	0.219 (0.124)	0.206 (0.159)	0.235 (0.251)
Proportion of residents in professional occupations	-0.007 (0.568)	-0.042 (0.741)	0.019 (0.355)	0.060 (0.305)	-0.019 (0.554)	0.157 (0.224)
Proportion of white residents	-0.013 (0.728)	**0.063** * (0.060)	-0.069 (1.000)	0.045 (0.156)	**0.107** * (0.064)	-0.034 (0.763)
Neighborhood income						
Median household income	-0.017 (0.771)	-0.063 (0.988)	0.017 (0.312)	0.004 (0.467)	-0.022 (0.639)	0.035 (0.305)

Note: 1) The table reports the differences of the rates of change (pretest-posttest) between the treatment and control groups (treatment minus control) and the p-value of the one-tail Paired T-tests of the differences between the treatment and control groups. 2) * p-value < 0.1, ** p-value < 0.05, *** p-value <0.01.

Table 11 Paired T-tests Results of Hypotheses of Transit-Induced Gentrification and of Transit-Induced Upgrading (2000 – 2016)

Paired T-tests on Hypothesis Treatment > Control	All			Rail		
	All Treated	Gentrifiable Treated	Non-gentrifiable treated	All Treated	Gentrifiable Treated	Non-gentrifiable treated
	Census Block Groups (2000 - 2016)					
Counts of Census block groups	1513	692	821	1208	555	653
Indicators of Gentrification						
Housing						
Median property value	0.011 (0.208)	**0.091** *** (0.000)	-0.053 (1.000)	0.013 (0.191)	**0.097** *** (0.000)	-0.054 (1.000)
Median rent	-1.961 (0.833)	**0.029** * (0.068)	-3.780 (0.835)	-2.464 (0.834)	**0.036** * (0.052)	-4.785 (0.836)
Proportion of owner-occupied dwellings	0.507 (0.161)	-0.107 (0.752)	1.028 (0.136)	0.631 (0.162)	-0.143 (0.768)	1.293 (0.136)
Total occupied housing	0.772 (0.198)	-0.943 (0.900)	**2.217** * (0.077)	1.336 (0.116)	-0.706 (0.803)	**3.071** * (0.057)
Demographic						
Total population	1.230 (0.215)	-1.337 (0.921)	3.393 (0.110)	1.922 (0.161)	-1.145 (0.855)	**4.529** * (0.096)
Proportion of residents with college education	**0.367** ** (0.034)	**0.930** ** (0.017)	-0.101 (0.944)	**0.504** ** (0.022)	**1.144** ** (0.017)	-0.035 (0.680)
Proportion of residents in professional occupations	**0.094** *** (0.001)	**0.228** *** (0.000)	-0.020 (0.696)	**0.133** *** (0.000)	**0.291** *** (0.000)	-0.001 (0.510)
Proportion of white residents	0.127 (0.219)	**0.410** * (0.081)	-0.111 (0.740)	0.196 (0.168)	**0.521** * (0.076)	-0.080 (0.643)
Economic						
Median household income	**0.052** *** (0.001)	0.022 (0.165)	**0.076** *** (0.000)	**0.075** *** (0.000)	**0.045** ** (0.044)	**0.100** *** (0.000)

Note: 1) The table reports the differences of the rates of change (pretest-posttest) between the treatment and control groups (treatment minus control) and the p-value of the one-tail Paired T-tests of the differences between the treatment and control groups. 2) * p-value < 0.1, ** p-value < 0.05, *** p-value <0.01.

Table 11 Paired T-tests Results of Hypotheses of Transit-Induced Gentrification and of Transit-Induced Upgrading (2000 - 2016) (Continued)

Paired T-tests on Hypothesis Treatment > Control	**BRT**			**High-end BRT**		
	All Treated	**Gentrifiable Treated**	**Non-gentrifiable treated**	**All Treated**	**Gentrifiable Treated**	**Non-gentrifiable treated**
	Census Block Groups (2000 - 2016)					
Counts of Census block groups	348	154	194	89	57	32
Indicators of Gentrification						
Housing						
Median property value	0.009 (0.371)	**0.078** * (0.077)	-0.044 (0.946)	-0.031 (0.638)	0.018 (0.442)	-0.116 (0.862)
Median rent	**0.043** * (0.076)	0.008 (0.410)	**0.072** * (0.060)	0.059 (0.141)	0.057 (0.217)	0.064 (0.219)
Proportion of owner-occupied dwellings	0.047 (0.303)	0.120 (0.111)	-0.012 (0.533)	0.070 (0.303)	**0.262** * (0.073)	-0.283 (0.929)
Total occupied housing	-1.093 (0.921)	-1.697 (0.881)	-0.614 (0.779)	**0.687** * (0.100)	-0.001 (0.506)	1.913 (0.101)
Demographic						
Total population	-1.118 (0.904)	-1.890 (0.868)	-0.505 (0.750)	**0.787** * (0.059)	-0.017 (0.596)	**2.219** * (0.056)
Proportion of residents with college education	-0.068 (0.768)	0.163 (0.151)	-0.247 (0.987)	**0.312** * (0.097)	**0.650** ** (0.023)	-0.280 (0.802)
Proportion of residents in professional occupations	-0.012 (0.586)	0.058 (0.291)	-0.067 (0.902)	-0.013 (0.548)	0.128 (0.211)	-0.265 (0.986)
Proportion of white residents	-0.122 (0.977)	-0.025 (0.579)	-0.200 (1.000)	0.076 (0.166)	**0.254** *** (0.006)	-0.242 (0.983)
Economic						
Median household income	-0.014 (0.698)	-0.079 (0.990)	0.109 (0.170)	-0.065 (0.883)	-0.086 (0.939)	-0.029 (0.597)

Note: 1) The table reports the differences of the rates of change (pretest-posttest) between the treatment and control groups (treatment minus control) and the p-value of the one-tail Paired T-tests of the differences between the treatment and control groups. 2) * p-value < 0.1, ** p-value < 0.05, *** p-value <0.01.

Table 11 Paired T-tests Results of Hypotheses of Transit-Induced Gentrification and of Transit-Induced Upgrading (2000 - 2016) (Continued)

Paired T-tests on Hypothesis Treatment > Control	**All**			**Rail**		
	All Treated	**Gentrifiable Treated**	**Non-gentrifiable treated**	**All Treated**	**Gentrifiable Treated**	**Non-gentrifiable treated**
	Census Tracts (2000 - 2016)					
Counts of Census tracts	853	393	460	698	332	366
Indicators of Gentrification						
Housing						
Median property value	**0.020** * (0.081)	**0.075** *** (0.001)	-0.028 (0.955)	0.021 (0.101)	**0.076** *** (0.002)	-0.030 (0.932)
Median rent	**0.043** *** (0.002)	**0.027** * (0.063)	0.057 (0.006)	**0.055** *** (0.001)	**0.033** * (0.052)	0.075 (0.003)
Proportion of owner-occupied dwellings	0.031 (0.279)	-0.019 (0.732)	0.074 (0.217)	0.039 (0.272)	-0.023 (0.755)	0.096 (0.210)
Total occupied housing	4.377 (0.166)	-0.219 (0.983)	8.304 (0.161)	5.348 (0.166)	-0.219 (0.966)	10.398 (0.162)
Demographic						
Total population	7.266 (0.162)	-0.332 (0.994)	13.758 (0.157)	8.886 (0.161)	-0.352 (0.990)	17.265 (0.157)
Proportion of residents with college education	**0.097** ** (0.028)	**0.257** *** (0.003)	-0.039 (0.779)	**0.136** ** (0.011)	**0.310** *** (0.002)	-0.022 (0.641)
Proportion of residents in professional occupations	**0.068** *** (0.001)	**0.139** *** (0.000)	0.007 (0.395)	**0.090** *** (0.000)	**0.171** *** (0.000)	0.0157 (0.293)
Proportion of white residents	0.025 (0.417)	0.155 (0.107)	-0.086 (0.668)	0.026 (0.430)	0.113 (0.211)	-0.054 (0.586)
Economic						
Median household income	**0.043** *** (0.000)	**0.032** ** (0.028)	**0.053** *** (0.003)	**0.054** *** (0.000)	**0.038** ** (0.022)	**0.069** *** (0.001)

Note: 1) The table reports the differences of the rates of change (pretest-posttest) between the treatment and control groups (treatment minus control) and the p-value of the one-tail Paired T-tests of the differences between the treatment and control groups. 2) * p-value < 0.1, ** p-value < 0.05, *** p-value <0.01.

Table 11 Paired T-tests Results of Hypotheses of Transit-Induced Gentrification and of Transit-Induced Upgrading (2000 – 2016) (Continued)

Paired T-tests on Hypothesis Treatment > Control	**BRT**			**High-end BRT**		
	All Treated	**Gentrifiable Treated**	**Non-gentrifiable treated**	**All Treated**	**Gentrifiable Treated**	**Non-gentrifiable treated**
	Census Tracts (2000 - 2016)					
Counts of Census tracts	182	77	105	50	28	22
Indicators of Gentrification						
Housing						
Median property value	0.015 (0.337)	**0.127** *** (0.001)	-0.065 (0.882)	-0.062 (0.691)	0.079 (0.140)	-0.261 (0.821)
Median rent	0.013 (0.251)	0.013 (0.332)	0.014 (0.306)	0.066 (0.116)	0.054 (0.200)	0.081 (0.204)
Proportion of owner-occupied dwellings	0.010 (0.387)	0.019 (0.390)	0.004 (0.457)	-0.057 (0.801)	-0.028 (0.603)	-0.095 (0.912)
Total occupied housing	-0.007 (0.526)	-0.147 (0.887)	0.096 (0.265)	-0.031 (0.646)	0.075 (0.161)	-0.166 (0.843)
Demographic						
Total population	0.029 (0.389)	-0.185 (0.921)	0.187 (0.112)	0.245 (0.141)	0.057 (0.106)	0.485 (0.177)
Proportion of residents with college education	-0.015 (0.572)	0.021 (0.445)	-0.042 (0.672)	0.217 (0.171)	0.316 (0.140)	0.090 (0.405)
Proportion of residents in professional occupations	-0.016 (0.638)	-0.004 (0.523)	-0.026 (0.650)	-0.010 (0.527)	-0.043 (0.630)	0.033 (0.454)
Proportion of white residents	0.016 (0.432)	**0.317** * (0.053)	-0.205 (1.000)	0.060 (0.225)	**0.182** * (0.059)	-0.096 (0.827)
Economic						
Median household income	-0.003 (0.552)	0.002 (0.480)	-0.006 (0.592)	-0.004 (0.530)	0.040 (0.288)	-0.060 (0.802)

Note: 1) The table reports the differences of the rates of change (pretest-posttest) between the treatment and control groups (treatment minus control) and the p-value of the one-tail Paired T-tests of the differences between the treatment and control groups. 2) * p-value < 0.1, ** p-value < 0.05, *** p-value <0.01.

Short-term (2000 – 2010)

Census Block Group Test Results. For all treated CBGs, only two indicators are significant: median property value and median household income. However, the results differ across different transit modes. For all treated CBGs served by rail, three indicators are significant: median property value, proportion of residents with college education, and median household income, suggesting more premiums of the sale price of housing, and faster growth of more affluent residents in the neighborhoods served by the rail. For all treated CBGs served by BRT, none of the indicators is significant, but for all treated CBGs served by high-end BRT, three demographic indicators (i.e., total population, proportion of residents with college education, and proportion of white residents) are significant, indicating faster growth of more affluent residents, disproportionally white, in the neighborhoods served by high-end BRT.

The test results are different between the gentrifiable treated and non-gentrifiable treated CBGs when testing between treated CBGs and their corresponding control groups. For the gentrifiable treated CBGs, four indicators are significant, including one housing indicator—median property value, and three demographic indicators—proportion of residents with college education, proportion of residents in professional occupations, and proportion of white residents. In contrast, for the non-gentrifiable treated, only median household income shows significantly faster increases or slower decreases than the corresponding control group.

These results for gentrifiable treated CBGs as a whole and non-gentrifiable treated CBGs as a whole, however, mask the differences across different transit modes within the two groups. For gentrifiable rail-served CBGs, five indicators of gentrification are significant, covering changes in housing (i.e., median property value), demographic (i.e., proportion of residents with college education, proportion of residents in professional occupations, and proportion of white residents), and neighborhood income (i.e., median household income) characteristics, four of which belongs to the five core indictors of gentrification. For non-gentrifiable rail-served CBGs, only total occupied units, which is not one of the five core indicators, is significant, with the p-value just equal to 0.1, the lowest level of significance. The gentrifiable BRT-served CBGs, however, only have two housing indicators that are slightly significant (i.e., significant at the 90% confidence level but not at the 95% confidence level): median property value and proportion of owner-occupied dwellings; whereas none of the indicators of gentrification is significant for non-gentrifiable BRT-served CBGs. For CBGs served by high-end BRT, all the significant indicators are demographic indicators. The gentrifiable CBGs served by high-end BRT have two indicators of gentrification that are significant: proportion of residents with college education and proportion of white residents; whereas the non-gentrifiable CBGs served by high-end BRT only have total population that is significant.

In sum, for the CBG analysis, only two indicators—median property value and median household income—are significant in the examinations of all treated group as a whole. All treated CBGs served by rail have more indicators that are significant than those served by BRT, and the significant indicators in rail-served CBGs cover changes in housing, demographic, and neighborhood income characteristics, most of which are core changes of gentrification. None of the indicators has been found significant by the tests for BRT-served CBGs, whereas for high-end BRT-served CBGs, only demographic indicators are significant. These tests identify a number of indicators in which significantly faster increases (or slower decreases) occurred in the all treated groups than their corresponding control groups. Since that, all treated CBGs include both gentrifiable and non-gentrifiable CBGs, these significantly faster increases (or slower decreases) can only be interpreted as TIU but not TIG, regardless of the rapid transit modes.

The results are different between the gentrifiable treated and non-gentrifiable treated subgroups. For gentrifiable treated CBGs as a whole, the significant indicators of gentrification cover the all core changes expected if the TIG hypothesis is true, and they give substantially faster increases (or slower decreases) in the gentrifiable treated CBGs than in the control group. For example, the rates of change in the gentrifiable treated CBGs are 17 percentage points higher for median property value and 76 percentage points higher for proportion of residents with college education compared to the control group. In contrast, only median household income is significant for non-gentrifiable treated CBGs as a whole to indicate the upgrading induced by transit, and the difference of rates of change is only six percentage points. The results are similar for rail-served subgroups of gentrifiable and non-gentrifiable. For BRT-served CBGs, however, only two housing indicators suggest gentrification in gentrifiable CBGs, and none of the indicators shows evidence of upgrading in non-gentrifiable CBGs. For high-end BRT-served CBGs, both the subgroups of gentrifiable and non-gentrifiable have demographic indicators that show evidence of TIG or TIU, but the indicators are not the same for the two subgroups. In addition, the differences in rates of change are all above 10 percentage points between the treatment and control groups for both BRT-served CBGs and high-end BRT served CBGs.

With regard to race, in gentrifiable CBGs served by rail and by high-end BRT, the proportion of white residents shows significantly faster increases (or slower decreases) than in their corresponding control groups, together with some core indicators of gentrification that are also significant. These results suggest that people of color may face more pressure of gentrification from the opening of transit stations than whites.

Census Tract Test Results. For all treated CTs, three indicators of gentrification are significant: median property value, proportion of residents in professional occupations, and median household income, all belonging to the five core indicators of gentrification, and suggesting more premiums of the sale price of housing and faster growth of more affluent residents in the neighborhoods served by the rapid transit stations. When looking at the subgroups of all treated CTs, the results differ across different transit modes. For all treated CTs served by rail, three indicators, which are the same with the three in all treated CTs as a whole, are significant. For all treated group served by BRT and all treated group served by high-end BRT, however, none of the indicators of gentrification is significant.

Within all treated CTs, the results are different between the gentrifiable treated and non-gentrifiable treated CTs when being tested with their corresponding control groups. For the gentrifiable treated, three indicators are significant, including one housing indicator—median property value, and two demographic indicators—proportion of residents in professional occupations, and proportion of white residents; whereas only median household income is significant for the non-gentrifiable treated.

These analysis results of all treated group as a whole, however, also have masked the differences across different transit modes. For gentrifiable rail-served CTs, three indicators of gentrification are significant, covering changes in housing (median property value) and demographic (proportion of residents in professional occupations, and proportion of white residents) characteristics, but not the neighborhood income; whereas for non-gentrifiable rail-served CTs, only median household income is significant. The gentrifiable BRT-served CTs also have three significant indicators of gentrification in the direction, covering housing and demographic characteristics: median property value, proportion of owner-occupied dwellings, and proportion of white residents; whereas none of the indicators of gentrification is significant for non-gentrifiable BRT-served CTs. For CTs served by high-end BRT, only proportion of white residents is significant in the gentrifiable treated, and none of the indicators is signification in the non-gentrifiable treated.

In sum, for CT analysis, three indicators—median property value, proportion of residents in professional occupation, and median household income—are significant in all treated group as a whole, covering changes in housing, demographic, and neighborhood income characteristics. Rail-served CTs have more indicators that are significant than BRT-served CTs, and the significant indicators are exactly the same with all treated CTs as a whole. No indicators have been found significant by the tests for BRT-served CTs and high-end BRT-served CTs. Similar to the CBG analysis, these tests identify a number of indicators in which significantly faster increases (or slower decreases) occurred in the all treated groups than their corresponding control groups. Since that all treated CTs includes both gentrifiable and non-gentrifiable CTs, these significant differences can only be interpreted as TIU but not TIG in the all treated CTs.

The test results are different between the gentrifiable treated and non-gentrifiable treated subgroups. For gentrifiable treated CTs as a whole, the significant indicators of gentrification cover most of the core changes expected if TIG occurred, but the differences in rates of change do not indicate large differences for residents' lives between the treatment and control groups. To be more specific, only median property value shows a moderately large difference in rates of change, specifically a difference of 13 percentage points between the treatment and control groups. The other two indicators (proportion of residents in professional occupations and proportion of white residents) are both below 10 percentage points. In contrast, only median household income is significant for non-gentrifiable treated CTs as a whole, and the difference in rates of change is only four percentage points. The results are the same for rail-served subgroups of gentrifiable and non-gentrifiable, with slight differences in the differences of rates of change when compared with the corresponding control groups. For BRT-served CTs, three indicators suggest gentrification in the gentrifiable CTs, covering housing and demographic characteristics; whereas none of the indicators shows evidence of TIU in the non-gentrifiable CTs. For high-end BRT-served CTs, only proportion of white residents is significant for the gentrifiable treated, and none is significant for the non-gentrifiable treated.

In fact, in all gentrifiable CTs newly served by rapid transit, regardless of mode, the proportion of white residents significantly increases faster (or decreases slower) than the corresponding control groups. The significance of the indicator—proportion of white residents— suggests that the station opening may disproportionally put more pressure of moving out of the gentrifiable RTS CTs on people of color or make people of color less likely to move in, compared with whites.

Comparison of results between Census block group test and Census tract test. Most previous empirical studies of gentrification have used Census tracts (CTs) as the areal unit of analysis. However, the geographic area of Census tracts are generally larger than the actual transit-served areas (i.e., usually defined as the areas of the half-mile walking distance from the rapid transit station), which means that not all the blocks/residents in the Census tracts contiguous to rapid transit stations are served by the stations. Therefore, in this dissertation, I use a smaller geographic unit—Census block groups (CBGs)—for the examinations of TIG hypothesis. To find whether the results of analysis differ between CBGs and CTs, the same research design is applied to both of them.

Generally speaking, the analysis of CBGs and analysis of CTs give similar results. First, more evidence of TIG has been found in gentrifiable neighborhoods served by rail than by BRT. Second, more evidence of upgrading induced by transit has been found in gentrifiable neighborhoods than in non-gentrifiable neighborhoods, especially for rail served neighborhoods, suggesting that the new transit stations would be more likely to induce gentrification in gentrifiable neighborhoods, but less likely to induce upgrading in non-gentrifiable neighborhoods. However, some differences exist between the analysis of CBGs and of CTs. For example, the evidence of TIG is more substantial for gentrifiable CBGs served by rail, than for gentrifiable CTs served by rail, with more significant indicators of gentrification and larger differences in rates of change for those significant indicators. BRT-served CBGs only show significantly faster increases (or slower decreases) of median property value in the gentrifiable and of median rent in the non-gentrifiable, with no other indicators significant; whereas BRT-served CTs only show significantly faster increases (or slower decreases) of median property value and proportion of white residents in the gentrifiable. High-end BRT-served CBGs show significantly faster increases in more affluent residents, disproportionally white, but the evidence is less substantial for high-end BRT-served CTs, even though the CTs also show disproportionate increases of whites. Therefore, when moving further away from the rapid transit stations, the neighborhoods could be affected differently by the opening of a station. Using a smaller areal unit of analysis (i.e., CBGs) results increases the validity of the results of the tests of the TIG hypothesis.

Long-term (2000 – 2016)

The Great Recession (2007-2009) was a period of severe economic downturn caused by bursting of housing bubble that led to a global financial crisis. Even though in the selection of control groups, two indicators (change of unemployment rate and change of affordable mortgage rate) have been used to control for the impact of the Great Recession, it is likely that in 2010, the housing market was not fully recovered. This fact raises the risk of bias in the TIG examinations. Therefore, this study also undertakes longer-term examinations (2000 – 2016) on TIG hypothesis to see the validation of the short-term examinations (2000 – 2010).

Census Block Group Test Results. In the long-term, for all treated group as a whole, three indicators of gentrification are significant: proportion of residents with college education, proportion of residents in professional occupations, and median household income, suggesting a faster growth of more affluent residents with higher income or income potential. The long-term analysis also shows differ results across different transit modes. For all treated group served by rail, three indicators are significant, which are the same as the significant indicators for all treated group as a whole. For all treated group served by BRT, only median rent is significant; whereas for all treated group served by high-end BRT, three indicators (i.e., total occupied housing, total population, and proportion of residents with college education) are significant, indicating the faster growth of more affluent residents and occupied housing units, in the neighborhoods served by high-end BRT.

Within all treated CBGs, different results are found between the gentrifiable treated and non-gentrifiable treated CBGs when being tested with their corresponding control groups. For the gentrifiable treated, five indicators are significant, including two housing indicator—median property value and median rent, and three demographic indicators—proportion of residents with college education, proportion of residents in professional occupations, and proportion of white residents. In contrast, only total occupied housing and median household income are significant for the non-gentrifiable treated.

Similar to the short-term analysis, the analyses of gentrifiable treated and non-gentrifiable treated subgroups as a whole mask the differences across different transit modes. For gentrifiable rail-served CBGs, six indicators of gentrification are significant, including all the five core indicators (i.e., median property value, median rent, proportion of residents with college education, proportion of residents in professional occupations, and median household income) and proportion of white residents; whereas for non-gentrifiable rail-served CBGs, only total occupied units and total population are slightly significant (i.e., significant at the 90% confidence level but not at the 95% confidence level), and none of them belongs to the five core indicators. The gentrifiable BRT-served CBGs, however, have only one housing indicator—median property value, that is slightly significant; whereas only median rent is slightly significant for non-gentrifiable BRT-served CBGs. For CBGs served by high-end BRT, the gentrifiable CBGs have three indicators significant, including one housing indicator (proportion of owner-occupied dwellings) and two demographic indicators (proportion of residents with college education, and proportion of white residents); whereas the non-gentrifiable CBGs only have total population that is significant.

In sum, for CBG analysis, three indicators—proportion of residents with college education, proportion of residents in professional occupations, and median household income—are significant in all treated group as a whole, suggesting faster increases of more affluent residents in the treatment group than the control group as a whole. Rail-served CBGs have more indicators that are significant than BRT, and the indicators cover changes in demographic, and neighborhood income, but not housing characteristics. Only median rent has only been found significant by the tests for BRT-served CBGs; whereas for high-end BRT-served CBGs, three indicators are significant, including total occupied housing, total population, and proportion of residents with college education, suggesting faster growth of residents with higher income potential. Similar to the short-term analysis, these tests identify a number of indicators in which significantly faster increases (or slower decreases) occurred in the all treated groups than their corresponding control groups. Since all treated CBGs includes both gentrifiable and non-gentrifiable CBGs, these significantly faster increases (or slower decreases) can only be interpreted as TIU but not TIG.

The test results are different between the gentrifiable treated and non-gentrifiable treated subgroups. For gentrifiable treated CBGs as a whole, the significant indicators of gentrification cover all the changes expected in core indicators if TIG occurred, except median household income. The differences in rates of change between the gentrifiable treated CBGs and their control groups are small for housing indicators (i.e., median property value: nine percentage points; median rent: three percentage points), but large for demographic indicators (i.e., proportion of residents with college education: 93 percentage points; proportion of residents in professional occupations: 23 percentage points; proportion of white residents: 41 percentage points). In contrast, only total occupied housing (with a difference of 221 percentage points) and median household income (with a difference of eight percentage points) are significant for non-gentrifiable treated CBGs as a whole. The evidence of TIG is more substantial for the gentrifiable rail-served CBGs than all gentrifiable treated as a whole, with all the five core indicators of gentrification are significant, and the differences in rates of change are also large for demographic indicators, but small for indicators of housing and neighborhood income. The non-gentrifiable CBGs served by rail, however, only have three indicators that are significant: total occupied housing, total population, and median household income, with only one belonging to the five core indicators of gentrification but the differences in rates of change are large for total occupied housing units (307 percentage points) and total population (453 percentage points). For BRT-served CBGs, only median property value suggests gentrification in gentrifiable CBGs and only median rent suggests upgrading in non-gentrifiable CBGs, and both the differences are small. For high-end BRT-served CBGs, the subgroup of gentrifiable shows faster increases in proportion of owner-occupied dwellings, proportion of residents with college education, and proportion of white residents than the corresponding control group; whereas the subgroup of non-gentrifiable only show faster growth of total population than the corresponding control group. All the significant indicators of gentrifiable and non-gentrifiable show large differences in rates of change between the treatment and control groups for CBGs served by high-end BRT.

With regard to race, only in gentrifiable CBGs served by rail and by high-end BRT, the proportion of white residents increases significantly faster (or decreases slower) than in their corresponding control groups, together with some core indicators of gentrification that are also significant. These results suggest that people of color may be more vulnerable to TIG than whites.

Census Tract Test Results. For all treated group, all the five core indicators of gentrification are significant: median property value, median rent, proportion of residents with college education, proportion of residents in professional occupations, and median household income. When looking at the subgroups of all treated CTs, the results differ across different transit modes. For all treated group served by rail, four indicators are significant: median rent, proportion of residents with college education, proportion of residents in professional occupations, and median household income, and all the four belongs to the five core indicators of gentrification. For all treated group served by BRT and all treated group served by high-end BRT, however, none of the indicators of gentrification is significant.

Within all treated CTs, the results are different between the subgroups of gentrifiable treated and of non-gentrifiable treated. For the gentrifiable treated, all the five core indicators of gentrification are significant: median property value, median rent, proportion of residents with college education, proportion of residents in professional occupations, and median household income. In contrast, only median household income is significant for the non-gentrifiable treated.

These analysis results of all treated group as a whole, however, also have masked the differences across different transit modes. For gentrifiable rail-served CTs, all the five core indicators of gentrification are significant; whereas for non-gentrifiable rail-served CTs, only median household income is significant. The gentrifiable BRT-served CTs only have two indicators of gentrification significant: median property value and proportion of white residents; whereas none of the indicators of gentrification is significant for non-gentrifiable BRT-served CTs. For CTs served by high-end BRT, only proportion of white residents is slightly significant in the gentrifiable treated, and none of the indicators is signification in the non-gentrifiable treated.

In sum, for CT analysis, all the five core indicators are significant in all treated group as a whole. Rail-served CTs have more indicators that are significant than BRT-served CTs. No indicators have been found significant by the tests for both BRT-served CTs and high-end BRT-served CTs. Similar to the analysis of CBGs, these tests identify a number of indicators in which significantly faster increases (or slower decreases) occurred in the all treated groups than their corresponding control groups. Because all treated CTs include both gentrifiable and non-gentrifiable CTs, these significant differences can only be interpreted as TIU but not TIG.

The results are different, however, between the gentrifiable treated and non-gentrifiable treated subgroups. For gentrifiable treated CTs, all the five core indicators of gentrification stay significant with large differences in rates of change between treatment and control groups in demographic indicators but small differences in indicators of housing and neighborhood income. In contrast, only median household income is significant for non-gentrifiable treated CTs, and the difference in rate of changes is small. The results are the same for rail-served subgroups of gentrifiable and non-gentrifiable with slight differences in the differences in rates of change between treatment and control groups. For BRT-served CTs, only two indicators suggest gentrification in gentrifiable CTs, indicating more premiums are added to the sales price of housing (13 percentage points), and faster growth in proportion of white residents (32 percentage points); whereas none of the indicators shows evidence of TIG in non-gentrifiable CTs. For high-end BRT-served CTs, only proportion of white residents is significant for the subgroup of gentrifiable treated (18 percentage points higher in the treatment than the control), and none of the indicators is significant for the subgroup of non-gentrifiable treated.

With regard to race, only in gentrifiable CTs served by BRT and by high-end BRT, the proportion of white residents shows significantly faster increases (or slower decreases) than in their corresponding control groups. However, few core indicators of gentrification are also significant, except the median property value in BRT-served CTs.

Comparison of results between Census block group test and Census tract test. Similar to the short-term analysis, I also conducted the examinations of TIG hypothesis using two levels of geographic unit—Census block groups (CBGs) and Census tracts (CTs) under the same research design. Generally speaking, the analysis of CBGs and analysis of CTs give similar results. First, more evidence of TIG has been found in gentrifiable neighborhoods served by rail than by BRT. Second, gentrifiable neighborhoods have more evidence of upgrading than non-gentrifiable neighborhoods, especially for the rail-served, and this result suggests that the new transit stations would be more likely to induce gentrification in gentrifiable neighborhoods, but less likely to induce upgrading in non-gentrifiable neighborhoods. Third, the differences in rates of change between the treatment and control groups are large for demographic indicators but small for indicators of housing and neighborhood income with regard to the TIG in gentrifiable neighborhoods. In the meantime, however, some differences also exist between the analysis of CBGs and of CTs in the long-term analyses. For example, even though both the analysis of CBGs and analysis of CTs show significance in all the five core indicators of gentrification, analysis of CBGs shows faster growth of white residents in rail-served neighborhoods than their corresponding control group, but the analysis of CTs does not, suggesting people of color in neighborhoods adjacent to the rail stations are more vulnerable to TIG than neighborhoods farther away from the stations. High-end BRT-served CBGs show significantly faster increases in residents with higher income potential and who are disproportionately white. However, almost none of the indicators of income potential is significant for high-end BRT-served CTs, regardless of gentrifiability, and the proportion of white residents is the only significant indicators for the gentrifiable CTs served by high-end BRT. Therefore, when moving further away from the rapid transit stations, the impact of open of stations almost disappear for high-end BRT-served neighborhoods. The long-term analysis also confirms that using a smaller areal unit of analysis (i.e., CBGs) would give more accurate examination results of the TIG hypothesis, especially for the high-end BRT, whose service radius is usually supposed to be smaller than the rail transit.

Comparisons between short- and long-term analyses.

The long-term analysis and short-term analysis are generally consistent in the overall picture of Transit-Induced Gentrification (TIG). First, more evidence of TIG has been found in gentrifiable neighborhoods served by rail than by BRT. Second, more evidence of upgrading induced by transit has been found in gentrifiable neighborhoods than in non-gentrifiable neighborhoods, especially for the rail-served (Table 10 and Table 11), suggesting the new rapid transit stations are more likely to induce gentrification in gentrifiable neighborhoods but less likely to induce upgrading in non-gentrifiable neighborhoods. The long-term analysis, however, generally offers more evidence of TIG than the short-term analysis.

Census Block Group Comparisons. The long-term analysis results are generally consistent with the short-term results for CBG analysis, but also generally offer more evidence of TIG in gentrifiable CBGs.

For all treated CBGs as a whole, the short-term analysis only shows significance in two indicators of gentrification: median property value and median household income (Table 10); whereas the long-term analysis adds evidence of upgrading induced by transit through the two core demographic indicators of gentrification: proportion of residents with college education and proportion of residents in professional occupations, even though the median property value becomes insignificant (Table 11). For rail-served CBGs as a whole, three indicators are significant in the short-term analysis: median property value, proportion of residents with college education, and median household income; whereas the long-term analysis adds proportion of residents in professional occupations, but miss median property, when comparing with the short-term analysis in terms of significance. For BRT-served CBGs as a whole, none of the indicators is significant in short-term analysis, but median rent becomes slightly significant (i.e., significant at the 90% confidence level but not at the 95% confidence level) in the long-term analysis. For high-end BRT-served CBGs as a whole, the significant indicators of gentrification are all demographic indicators in short-term analysis; whereas the long-term analysis shows slightly significant faster growth of total occupied housing than the corresponding control group, but the faster growth of proportion of white residents becomes not significant.

The long-term analysis gives consistent but stronger evidence of TIG in gentrifiable CBGs than the short-term analysis, especially for the rail-served (Table 11). For gentrifiable treated CBGs as a whole, all significant indicators in the short-term analysis stay significant in the long-term analysis, and the median rent becomes slightly significant in the long-term analysis. So do the gentrifiable CBGs served by rail. For gentrifiable CBGs served by BRT, the evidence of TIG becomes less, however, with two indicators (i.e., median property value and proportion of owner-occupied housing) slightly significant in the short-term analysis, but only median property value stays slightly significant in the long-term analysis. For gentrifiable CBGs served by high-end

BRT, in addition to the two significant indicators (i.e., proportion of residents with college education and proportion of white residents) in the short-term analysis, the proportion of owner-occupied dwellings also becomes significant in the long-term analysis. The non-gentrifiable treated CBGs, regardless of transit mode, show little evidence of TIU in the long-term analysis compared to the short-term analysis.

Census Tract Comparisons. Comparing to the comparisons of CBGs, the stronger evidence of TIG in long-term analysis than the short-term analysis is more substantial for comparisons of gentrifiable CTs, especially for rail-served.

For all treated CTs as a whole, the short-term analysis only show significance in three indicators: median property value, proportion of residents in professional occupations, and median household income; whereas the long-term analysis adds evidence of the upgrading induced by transit through the other two core indicators: median rent and proportion of residents with college education. For rail-served CTs as a whole, three indicators are significant in the short-term analysis: median property value, proportion of residents in professional occupations, and median household income. The long-term analysis adds median rent and proportion of residents with college education, but does not include median property values. For BRT-served CTs as a whole, both the short- and long-term analyses show none of the indicators is significant, and so do the high-end BRT-served CTs as a whole.

Similar to the analysis of CBGs, the analysis of CTs also gives consistent but stronger evidence of TIG in the gentrifiable neighborhoods over long-term than over short-term. For gentrifiable treated CTs as a whole, the three indicators that belong to the core indicators of gentrification over short-term remain significant over long-term, and the other two core indicators of gentrification—median rent and median household income—are added to the set of indicators that are significant. This is also true for the gentrifiable CTs served by rail. However, in the gentrifiable CTs served by rail, the proportion of white residents is slightly significant over short-term, but becomes not significant over long-term. Even for the gentrifiable CTs, both the BRT-served CTs and high-end BRT served CTs still show much less evidence of TIG than the rail-served CTs over long-term, which is the same as over short-term.

Summary of the results

In sum, the results of the Paired T-tests confirm that the Transit-induced Gentrification (TIG) is more likely to occur in gentrifiable neighborhoods, but the TIU is less likely to occur in non-gentrifiable neighborhoods, regardless of the areal unit of analysis (i.e., CBGs or CTs) (Table 12). To be more specific, the gentrifiable neighborhoods have more indicators that significantly increase faster or decrease slower in the treatment group than in the corresponding control group; whereas the non-gentrifiable neighborhoods have much less indicators that are significant. In addition, gentrifiable neighborhoods served by rail show more evidence of TIG than those served by BRT, and indicators of gentrification cover all or most of the five core indicators for gentrifiable neighborhoods served by rail, regardless of the areal unit of analysis. In the analysis of CBGs, gentrifiable neighborhoods served by high-end BRT also show more evidence of TIG, mainly in demographic indicators, than the gentrifiable neighborhoods served by BRT (i.e., BRT as a whole, including high-end BRT); whereas in the analysis of CTs, both gentrifiable neighborhoods served by high-end BRT and BRT show little evidence of TIG. One notable thing is that all the high-BRT stations in the study period are stations of the Metro Silver Line in Los Angeles, and it could only reflect the TIG circumstance unique to the MSA and system. The results over long-term are generally consistent with the results over short-term, and show stronger evidence of TIG than over short-term in the rail-served neighborhoods that are gentrifiable, regardless of the areal unit of analysis.

Table 12 Significant Indicators in the Paired T-tests

Significant indicators for hypothesis: Treatment > Control		Census Block Groups: All Treated	Census Block Groups: Gentrifiable treated	Census Block Groups: Non-gentrifiable treated
2000 – 2010	**All**	Core (2): median property value, median household income; Other (0): *None*	Core (3): median property value, % of residents with college education, % of residents in professional occupations; Other (1): % of white residents;	Core (1): median household income; Other (0): *None*
	Rail	Core (3): median property value, % of residents with college education, median household income; Other (0): *None*	Core (4): median property value, % of residents with college education, % of residents in professional occupations, median household income; Other (1): % of white residents;	Core (1): median household income; Other (1) : total occupied housing;
	BRT	*None*	Core (1): median property value; Other (1): % of owner-occupied dwellings;	*None*
	High-end BRT	Core (1): % of residents with college education; Other (2): total population, % of white residents;	Core (1): % of residents with college education; Other (1): % of white residents;	Core (0): *None* Other (1): total population;

Table 12 Significant Indicators in the Paired T-tests (Continued)

Significant indicators for hypothesis: Treatment > Control		Census Block Groups: All Treated	Census Block Groups: Gentrifiable treated	Census Block Groups: Non-gentrifiable treated
2000 – 2016	**All**	Core (3): % of residents with college education, % of residents in professional occupations, median household income; Other (0): *None*	Core (4): median property value, median rent, % of residents with college education, % of residents in professional occupations; Other (1): % of white residents;	Core (1): median household income; Other (1) : total occupied housing;
	Rail	Core (3): % of residents with college education, % of residents in professional occupations, median household income; Other (0): *None*	Core (5): median property value, median rent, % of residents with college education, % of residents in professional occupations, median household income; Other (1): % of white residents;	Core (1): median household income; Other (2): total housing units, total population;
	BRT	Core (1): median rent; Other (0): *None*	Core (1): median property value; Other (0): *None*	Core (1): median rent; Other (0): *None*
	High-end BRT	Core (1): % of residents with college education; Other (2): total housing units, total population;	Core (1): % of residents with college education; Other (2): % of owner-occupied dwellings, % of white residents;	Core (0): *None* Other (1): total population;

Table 12 Significant Indicators in the Paired T-tests (Continued)

Significant indicators for hypothesis: Treatment > Control		Census Tracts All Treated	Census Tracts Gentrifiable treated	Census Tracts Non-gentrifiable treated
2000 – 2010	**All**	Core (3): median property value, % of residents in professional occupations, median household income; Other (0): *None*	Core (2): median property value, % of residents in professional occupations; Other (1): % of white residents;	Core (1): median household income; Other (0): *None*
	Rail	Core (3): median property value, % of residents in professional occupations, median household income; Other (0): *None*	Core (2): median property value, % of residents in professional occupations; Other (1): % of white residents;	Core (1): median household income; Other (0): *None*
	BRT	*None*	Core (1): median property value; Other (2): % of owner-occupied dwellings, % of white residents;	*None*
	High-end BRT	*None*	Core (0): *None* Other (1): % of white residents;	*None*

Table 12 Significant Indicators in the Paired T-tests (Continued)

Significant indicators for hypothesis: Treatment > Control		Census Tracts: All Treated	Census Tracts: Gentrifiable treated	Census Tracts: Non-gentrifiable treated
2000 – 2016	**All**	Core (5): median property value, median rent, % of residents with college education, % of residents in professional occupations, median household income; Other (0): *None*	Core (5): median property value, median rent, % of residents with college education, % of residents in professional occupations, median household income; Other (0): *None*	Core (1): median household income; Other (0): *None*
	Rail	Core (4): median rent, % of residents with college education, % of residents in professional occupations, median household income; Other (0): *None*	Core (5): median property value, median rent, % of residents with college education, % of residents in professional occupations, median household income; Other (0): *None*	Core (1): median household income; Other (0): *None*
	BRT	*None*	Core (1): median property value; Other (1): % of white residents;	*None*
	High-end BRT	*None*	Core (0): *None* Other (1): % of white residents;	*None*

3.6 Discussion and Conclusions

Previous studies have reached different conclusions on the evidence in support of the TIG hypothesis, but these differences may be associated with differences in gentrification definitions and measures, research designs, and study areas. In general, they have found that the TIG is evident in some cities or metros, but is not in some other cities or metros. Even in the same cities or metros, the conclusions of TIG also show difference across different studies (Padeiro et al., 2019).

This study applies a quasi-experimental design to examine the TIG hypothesis in all neighborhoods newly served by the rapid transit stations that opened from 2000 through 2009 in the United States. The study is targeted on giving better understanding on the impact of newly opened rapid transit stations on the neighborhoods they served in the United States under the same research design. The pretest-posttest comparisons are made between the treatment groups, which are the neighborhoods newly served by the rapid transit stations opened during 2000 to 2009 in the U.S., and their corresponding control groups selected by the nonparametric propensity score matching, which controls for the characteristics of neighborhoods prior to the open of rapid transit stations and the impact of Great Recession.

In general, this study confirms the heterogeneity of findings on the TIG hypothesis, and thus indicates that gentrification may occur but is not inevitable within the rapid-transit-served (RTS) areas.

1) For all neighborhoods (CBGs[3]) served by rapid transit, only the rates of change for median property value and neighborhood income are significantly different from the rates for the control group over short-term. The results over long-term add one more indicator that is significant—the proportion of residents in professional occupations. These results suggest some evidence of neighborhood upgrading induced by transit (interpreted as gentrification induced by transit in gentrifiable neighborhoods)—faster increases (or slower decreases) of property value and neighborhood income than the control group, but the evidence does not cover all core indicators of gentrification.

2) Among different rapid transit modes, rail transit shows most evidence of inducing gentrification in gentrifiable neighborhoods, and BRT shows least. The significant indicators of

[3] Here only results of CBGs are presented, because as discussed in previous sections, CBGs give more precise definition of rapid-transit-served (RTS) areas.

gentrification of rail-served neighborhoods that are gentrifiable include all or most of the core indicators of gentrification: median property value, median rent, proportion of residents with college education, proportion of residents in professional occupations, and median household income. These significant indicators, together, confirm the faster increases (or slower decreases) of housing costs and proportion of more affluent residents with higher income or income potential in rail-served neighborhoods that are gentrifiable, especially over long-term. For gentrifiable neighborhoods served by high-end BRT, the significant indicators are concentrated in demographic indicators over short-term; whereas even though the housing indicators are added to the set of significant indicators over long-term, none of them belongs to the five core indicators of gentrification. For gentrifiable neighborhoods served by BRT, little evidence of TIG have been shown over both short- and long-term.

3) Even though the gentrifiable neighborhoods show evidence of TIG, especially in the rail-served neighborhoods, much less evidence of upgrading has been found in the non-gentrifiable neighborhoods that are newly served by the rapid transit stations. This result indicates that the rapid transit lines are more likely to induce gentrification in gentrifiable neighborhoods than TIU upgrading in non-gentrifiable neighborhoods.

4) The results of long-term examinations on TIG are generally consistent with the results of short-term examinations, but offer stronger evidence of gentrification. This stronger evidence over the long-term than over the short-term is more substantial in rail-served neighborhoods and more substantial for analysis of CTs than of CBGs. These results suggest the TIG could be more evident in rail-served neighborhoods and could extend further away from the rapid transit stations as time goes.

In addition, traditional gentrification studies usually use Census tracts (CTs) as the areal unit of analysis, including some TIG studies. However, my findings suggest the CTs are too large compared to the transit-served areas, and Census block groups (CBGs) would be more suitable. This study shows fewer indicators of gentrification are significant in the CT analysis than in the CBG analysis, especially over short-term. This result could attribute to the circumstance that the impact of new opened transit stations starts from the adjacent neighborhoods and then extends to the adjoining neighborhoods of the adjacent as time goes. In addition, little evidence has been found in high-end BRT served areas, regardless of short- or long-term examinations, when using CT as the areal unit of analysis. In contrast, the analysis of CBG in gentrifiable high-end BRT served areas suggests some evidence of gentrification in demographic indicators. This could result from that the impact of the high-end BRT stations are limited to their adjacent neighborhoods. The different findings between CBG and CT analyses suggest that for future studies of TIG, analysis using CBGs will give more valid results than using CTs.

The results of this study also show significantly faster increases (or slower decreases) of the proportion of white residents in gentrifiable CBGs served by rail transit or high-end BRT over both short-term and long-term, in gentrifiable CTs served by any of the rapid transit modes over short-term, and in gentrifiable CTs served by BRT or high-end BRT over long-term, compared to their corresponding control groups. These findings suggest that the people of color are more vulnerable to the TIG and may be at greater risk of displacement by new white residents.

One limitation of this study is the possible existence of endogeneity, which means that the design of the rapid transit lines could have considered the characteristics of the neighborhoods they would pass through, and these neighborhoods may have more potential in gentrification or have already been in the process of gentrification. Selecting the control groups by propensity score matching helps to control for the impact of endogeneity, but does not fully resolve the problem. Future studies may assess the Transit-Oriented Development (TOD) policies or other ways to control for this endogeneity. In addition, some rapid transit lines could have already caused the neighborhood change right after the publication of transit plans and before the transit opening. This may also increase the risk of bias of the conclusions. Finally, in this study, displacement is not included in the definition and measures of gentrification. Future studies could put more efforts in exploring the relationship between Transit-Induced Gentrification and the displacement of residents that are prior to the open of the transit.

These findings have implications for policy-makers and/or transit planners. For example, BRT, with lower probability of inducing gentrification, could reduce the likelihood of gentrification relative to rail transit, thus helping to sustain service to the most vulnerable. In addition, the gentrification in rail-served neighborhoods does not show significantly faster growth of total population and total occupied housing, but shows significantly faster increases in proportion of residents with college education, proportion of residents in professional occupations, proportion of white residents, and median household income, than their corresponding control groups. This result raises the concern over the potential displacement of lower-income residents and people of color prior to the open of rapid transit stations, especially for the gentrifiable neighborhoods. The potential risk of displacement in rail-served neighborhoods calls for suitable targeted policies to alleviate the impact, such as affordable housing and rent ceilings, to assist the most vulnerable residents, particularly people of color.

Chapter 4: What Factors Affect the Occurrence of Transit-Induced Gentrification in U.S. MSAs?

4.1 Introduction

In Chapter 3, I tested the Transit-Induced Gentrification (TIG) hypothesis with a quasi-experimental design and found the probability of TIG varies across different transit modes and over different periods. In addition, the indicators of gentrification perform differently in indicating gentrification. Paired means test provide evidence that TIG is more likely to occur in the gentrifiable neighborhoods near new rail transit stations and high-end BRT stops and little evidence of TIG near BRT stops that are not high-end systems. To be more specific, the impact of newly opened rail transit stations on the gentrifiable neighborhoods they serve are significant in all or most of the five core indicators of gentrification: median property value, median rent, proportion of residents with college education, proportion of residents in professional occupation, and median household income. In contrast, the impact of high-end BRT stations only show significant impact on the demographic characteristics, such as proportion of residents with college education and proportion of white residents in the gentrifiable neighborhoods it served. In addition, the analysis of Census block groups (CBGs) gives more valid results than the analysis of Census tracts (CTs), and more evidence of TIG is found over longer period of time.

A limitation of the Paired T-tests in Chapter 3 is that they do not specify which of the treated neighborhoods actually experienced TIG or TIU. The Paired T-tests do show the differences of the rates of change between some treated neighborhoods and the corresponding control groups are greater than the differences between other treated neighborhoods and the corresponding control groups. The tests also show that even for the same treatment group, different indicators perform differently in indicating TIG. These results suggest the likelihood of significant upgrading and gentrification varies among different neighborhoods. In light of this variation, more specific definition of the occurrence of TIG is needed for further exploration. Chapter 3 also has not identified specific factors within neighborhoods that affect the likelihood of TIG.

Chapter 4 is designed to answer this question. To be more specific, there are two major tasks of Chapter 4: 1) evaluate the probability of TIG in all neighborhoods that are newly served by rapid transit stations from 2000 through 2009 in the U.S.; and 2) identify and examine factors that could determine or affect the probability of TIG among rapid-transit-served (RTS) neighborhoods.

4.2 Definition of the Occurrence of Transit-Induced Gentrification

To assess factors associated with the occurrence of TIG in rapid-transit-served (RTS) neighborhoods, a summative measure of TIG is required. Here the RTS neighborhoods are defined as Census block groups (CBGs) because it gives more valid results than Census tracts (CTs). In Chapter 3, nine indicators of gentrification indicating changes of housing, demographic, and neighborhood income characteristics before and after the rapid station opened are used to measure gentrification. These indicators of gentrification provide a full picture of the characteristics indicating gentrification in the treated neighborhoods that are gentrifiable, but the nine indicators themselves without the quasi-experimental design (i.e., without comparing between the treatment and control groups) cannot validly support the causal relationship between transit and gentrification (i.e., cannot be the indicators of TIG). Therefore, to measure TIG, the comparisons between the treatment and control groups need to be subsumed. In addition, the nine indicators of gentrification are not always consistent in their direction and magnitude of changes for an individual gentrifiable CBG newly served by the rapid transit stations. This fact means that use of a particular indicator as the measure of whether TIG occurred will lead to instability in the TIG measurement. Therefore, one single or summative indicator (i.e., binary indicator of TIG) is needed to assess whether the changes observed meet the “threshold” of TIG in the RTS neighborhoods that are gentrifiable.

However, any threshold used to define the occurrence of TIG is somewhat arbitrary. Scholars have used various measures, most of which are summative indices, to define the occurrence of gentrification. These indices usually involve two major sets of characteristics: the changes in shelter/housing characteristics and the changes of income potential of residents. In addition to these two sets, the indicators of gentrification in Chapter 3 also include four other indicators: proportion of owner-occupied dwellings, total occupied housing, total population, and proportion of white residents. Based on these characteristics of gentrification, three summative indices with different thresholds are developed to define the occurrence of TIG to reduce the risk of bias by a single indicator.

The three summative indices are based on different combinations of the indicators of gentrification assessed in Chapter 3 (Table 13): shelter indicators, income potential indicators, and other indicators. The shelter indicators and the income potential indicators are the five core indicators of gentrification defined in Chapter 3. In Definition 1, for the CBGs in the treatment group (i.e., served by rapid transit stations), TIG is said to have occurred when at least one shelter indicator (Set **A**) and one income potential indicator (Set **B**) meet the threshold α, which states the rate of change for the indicator for the CBG in the treatment group has to be greater than the mean rate of change in its corresponding control group. Binary measures of gentrification that are similar to Definition 1 have been commonly used in previous studies (e.g. Ding et al., 2016), in which the rates of change in the treatment group are usually compared with the city medians instead of the rates of change in the corresponding control groups in this dissertation. However, this binary measure of gentrification could be criticized because it is less likely to require the substantial differences between the treatment and control groups when only requiring the treatment has greater rates of change than the control for at least two indicators (one shelter indicator and one income potential indicator), no matter how small the differences of the rates of change are. Therefore, another two binary measures of TIG that are more stringent are used as well, with adding criteria from two different perspectives.

Definition 2 follows the criteria of Definition 1 and adds another criterion, which requires at least five indicators of the nine indicators, regardless of set, meet the threshold α, so that the key is a majority of indicators meet the threshold α. Instead of the rate of change for the indicator for the CBG in the treatment group only being greater than the mean rate of change in its corresponding control group in threshold α, threshold β requires the differences have to be significantly greater than the critical value at the 90% confidence level for the one-tail test.

The CBG in the treatment group is defined as TIG occurred in Definition 3 when at least one shelter indicator (Set **A'**) and one income potential indicator (Set **B'**) meet the threshold β. In Definition 3, the requirement of a majority of indicators meeting the threshold β is not included, because including the requirement will give very few instances of gentrification, which could be counterfactual.

Table 13 Three Definitions of the Occurrence of Transit-Induced Gentrification

Definitions of Sets of Census Block Groups (CBGs) in Treatment Group			**Definitions of Occurrence of Transit-Induced Gentrification**		
Groups of Indicators	**Standards of TIG occurrence for a typical CBG *i* in treatment group**				
	Threshold α: The change rate of indicator *j* for CBG *i* > Mean change rate of indicator *j* for the three corresponding CBGs in the control group	**Threshold β:** The change rate of indicator *j* for CBG *i* – Mean change rate of indicator *j* for the three corresponding CBGs in the control group > The critical value at the 90% confidence level for the one-tail test of each indicator			
Shelter Indicators: 1) *median property value*, and 2) *median rent*.	Set **A**: CBGs with true for at least one indicator	Set **A'**: CBGs with true for at least one indicator	**Definition 1 (Two-criterion definition):** Intersection set of Set **A** and Set **B** (i.e., $\mathbf{A} \cap \mathbf{B}$)	**Definition 2 (Three-criterion definition):** Intersection set of Set **A,** Set **B**, and Set **C** (i.e., $\mathbf{A} \cap \mathbf{B} \cap \mathbf{C}$)	**Definition 3 (Significance-criterion definition):** Intersection set of Set **A'** and Set **B'** (i.e., $\mathbf{A'} \cap \mathbf{B'}$)
Income Potential Indicators: 1) *proportion of residents with college education*, 2) *proportion of residents in professional occupations*, and 3) *median household income*.	Set **B**: CBGs with true for at least one indicator	Set **B'**: CBGs with true for at least one indicator			
All Indicators: Shelter indicators – 1) *median property value*, 2) *median rent*; Income potential indicators – 3) *proportion of residents with college education*, 4) *proportion of residents in professional occupations*, 5) *median household income*; Other indicators – 6) *proportion of owner-occupied dwellings*, 7) *total occupied housing*, 8) *total population*, and 9) *proportion of white residents*.	Set **C**: CBGs with true for at least five indicators				

4.3 Transit-Induced Gentrification (TIG) across Transit Modes

Each of the three definitions of TIG occurrence is applied to both the short-term (2000 – 2010) and the long-term (2000 – 2016) analyses. To get a full picture, the three definitions of TIG, which are targeted on the gentrifiable neighborhoods only, are also used to measure the more general Transit-Induced Upgrading (TIU) in all treated neighborhoods, which include both gentrifiable and non-gentrifiable neighborhoods that are newly served by rapid transit stations. Table 14 summarizes the percentages of CBGs that experienced TIU among the RTS CBGs (i.e., all treated) and that experienced TIG among the gentrifiable RTS CBGs (i.e., gentrifiable treated). The percentages are reported for four different groups of CBGs: all RTS CBGs, rail-served CBGs, BRT-served CBGs, and high-end BRT-served CBGs. These three definitions give different results with regard to the scales of percentages and the comparisons across different transit modes. In general, use of Definition 1 results in the highest incidence of TIG, followed by Definition 2 and Definition 3. With Definition 1, well over than half and as many as two-thirds of the CBGs experienced TIG, while with Definitions 2 and Definition 3, fewer than half experienced TIG (Table 14).

Definition 1, the two-criterion definition, establishes the lowest threshold for the occurrence of TIG among the three definitions. This two-criterion definition only requires the CBG in the treatment group to have at least one shelter indicator and at least one income potential indicator that increased faster (or decreased slower) than the mean change of its corresponding three CBGs of the control group, no matter how small the difference in rates of change. Use of this definition suggests that TIU occurred in 57.1-67.4% of CBGs in the treatment groups and TIG occurred in 52.8-67.0% of gentrifiable CBGs in the treatment groups. The percentages are higher in gentrifiable treated CBGs than the all treated CBGs for both short- and long-term analyses, and are higher in long-term analysis than in short-term analysis. To be more specific, 60.3% of all treated CBGs experienced TIU and 62.3% of gentrifiable treated CBGs experienced TIG in the short-term, regardless of transit modes. The percentages are 63.7% and 66.0% in the long-term analysis, respectively.

The percentages are slightly higher in rail-served CBGs than in BRT-served CBGs, regardless of gentrifiability and for both the short- and long-term. In addition, for both the rail- and BRT-served CBGs, the percentages are slightly higher over the long-term than the short-term. For the high-end BRT-served CBGs, however, a higher percentage of CBGs has been found over the short-term than the long-term, regardless of gentrifiable or not. In the meantime, the percentages of high-end BRT-served CBGs are almost the highest among all transit modes over the short-term, but become the lowest over the long-term, for both all treated and gentrifiable treated groups. This large fluctuation may partly result from the small sample size of high-end BRT-served CBGs.

Definition 2, the three-criterion definition of TIG occurrence, adds another criterion to Definition 1, which makes it more stringent and, all else equal, likely to reduce percentages of CBGs in which TIG is believed to have occurred. Specifically, Definition 2 requires the CBGs in the treatment group to have at least five out of nine indicators of gentrification that increase faster (or decrease slower) than its corresponding control group. Instead of a majority of all gentrifiable CBGs experiencing TIG (i.e., 60%) defined as Definition 1, fewer than half – 40%, or less than a majority – experienced TIG based on the Definition 2. This criterion removes about 20% of the gentrifiable CBGs from being defined as having experienced TIG (compared to Definition 1). To be more specific, the use of Definition 2 suggests that TIU occurred in 31.2-43.6% of CBGs in the treatment groups and TIG occurred in 33.7-50.5% of gentrifiable CBGs in the treatment groups. Similar to the percentages under Definition 1, the percentages under Definition 2 are also higher in gentrifiable treated CBGs than the all treated CBGs for both the short- and long-term, and are higher over the long-term than over the short-term. In the short-term, 40.6% of all treated CBGs experienced TIU and 41.2% of gentrifiable treated CBGs experienced TIG, regardless of transit modes. The percentages are 43.6% and 48.3% in the long-term, respectively.

Similar to Definition 1, the percentages of Definition 2 are also higher in rail-served CBGs than in BRT-served CBGs, regardless of gentrifiability and for both the short- and long-term. In addition, for both the rail- and BRT-served CBGs, the percentages are higher over the long-term than the short-term. For the high-end BRT-served CBGs, however, a higher percentage of CBGs that experienced TIU over the short-term than over the long-term for all treated CBGs, and the percentages of gentrifiable treated CBGs that experienced TIG are the same for both the short- and long-term. The high-end BRT-served CBGs, as a subgroup of the BRT-served CBGs, have higher percentages over the short-term, but lower percentages over the long-term than the BRT-served CBGs, regardless of gentrifiable or not. These results based on Definition 2 give most consistent conclusions with the examinations of TIG hypothesis in Chapter 3, among the three definitions.

Definition 3 of the TIG occurrence is similar to Definition 1, but establishes a more stringent threshold that is based on the Paired T-tests in Chapter 3 with involving the statistical significance. Specifically, Definition 3 requires that at least one shelter indicator and at least one income potential indicator have differences between the treatment and control that exceed the critical values at the 90% confidence level based on the one-tail test for the treatment greater than the control. Use of this significance-criterion definition suggests that TIU occurred in 31.8-41.6% of CBGs in the treatment groups, and that TIG occurred in 38.0-46.8% of gentrifiable CBGs in the treatment groups. Similar to the other two definitions, the percentages are also higher in gentrifiable treated CBGs than the all treated CBGs for both short- and long-term, and are higher over the long-term than over the short-term. To be more specific, 35.6% of all treated CBGs experienced TIU and 38.2% of gentrifiable treated CBGs experienced TIG over the short-term, regardless of transit modes. The percentages are 38.4% and 44.4% over the long-term, respectively.

The percentages are higher in rail-served CBGs than in BRT-served CBGs, regardless of gentrifiability and for short-term, but for long-term, BRT-served CBGs have higher percentages than rail-served CBGs, regardless of gentrifiability. In addition, for both the rail- and BRT-served CBGs, the percentages are higher over the long-term than over the short-term. For the high-end BRT-served CBGs, the comparisons are more varied. For example, among the treated CBGs, a higher percentage of CBGs served by high-end BRT experienced TIU compared to both the rail-served and BRT-served CBGs over the short-term. Over the long-term for all treated CBGs, however, the percentage of high-end BRT-served CBGs are higher than the rail-served CBGs and lower than the BRT-served CBGs, even though the differences of percentages are small. For gentrifiable treated CBGs, both the short- and long-term show the percentages of high-end BRT-served are in between the percentages of rail-served and of BRT-served, even though the rail-served CBGs have a higher percentage over the short-term but the BRT-served CBGs have a higher percentage over the long-term.

Even based on the Paired T-tests in Chapter 3, Definition 3 gives conclusions at odds with Chapter 3. For example, rail-served gentrifiable CBGs do not show substantial higher percentages of CBGs experienced TIG than BRT-served gentrifiable CBGs over both short- and long-term according to Definition 3, whereas more evidence of TIG are found in rail-served gentrifiable CBGs than BRT-served gentrifiable CBGs according to the Paired T-tests in Chapter 3. That inconsistency could result from the different critical values used in Definition 3 and in the Paired T-tests in Chapter 3. To be more specific, in Definition 3, all the CBGs in the treatment group, regardless of transit modes and gentrifiability, use the same critical value for each indicator of gentrification obtained from the Paired T-tests between all treated and the corresponding control when defining the TIG occurrence. In the Paired T-tests in Chapter 3, however, different critical values for each indicator are used for different transit modes and for different gentrifiability of CBGs.

Table 14 Percentages of Census Block Groups in the Treatment Group that experienced Transit-Induced Gentrification or Upgrading

Transit Modes	**All Treated**			**Gentrifiable Treated**		
	Count of CBGs	% upgraded		Count of CBGs	% gentrified	
		To 2010	To 2016		To 2010	To 2016
Definition 1: A ∩ B (two-criterion definition)						
All	1,513	60.3	63.7	692	62.3	66.0
Rail	1,208	60.5	64.8	555	63.6	67.0
BRT	348	60.3	61.2	154	57.1	63.6
High-end BRT	89	67.4	52.8	57	63.2	59.6
Definition 2: A ∩ B ∩ C (three-criterion definition)						
All	1,513	40.6	43.6	692	41.2	48.3
Rail	1,208	41.6	45.5	555	43.6	50.5
BRT	348	37.6	38.2	154	31.2	40.9
High-end BRT	89	39.3	33.7	57	38.6	38.6
Definition 3: A' ∩ B' (Significance criteria definition: at the 90% confidence level)						
All	1,513	35.6	38.4	692	38.2	44.4
Rail	1,208	36.2	38.0	555	39.6	44.0
BRT	348	34.5	41.1	154	31.8	46.8
High-end BRT	89	41.6	39.3	57	36.8	45.6

4.4 Determinants of the Occurrence of Transit-Induced Gentrification

4.4.1 Hypotheses

Evidence in Chapter 3 and Section 4.3 shows that the occurrence of TIG varies across different transit modes and across different types of neighborhoods for both the short-term (2000 – 2010) and long-term (2000 – 2016). These differences could be affected by both metropolitan area (MSA) characteristics and neighborhood characteristics. Therefore, this chapter is designed to identify the factors of MSAs and of neighborhoods that could affect the probability of TIG.

Two major hypotheses are examined in this chapter: 1) MSA characteristics, including both physical and socioeconomic characteristics, affect the probability of TIG; and 2) Neighborhood (CBG) characteristics, including the physical and socioeconomic characteristics, also affect the probability of TIG. The variables hypothesized to be associated with TIG are listed in Table 15.

Table 15 Independent Variables for the Hypothesis Tests

Metropolitan Area Characteristics	**Neighborhood (Census Block Group) Characteristics**
Physical	
1) Size (land areas, population size) 2) Transit infrastructure (count of rapid transit stations, existence of previous high-quality transit)	1) Location (distance to CBD / freeway) 2) Housing density 3) New transit mode 4) Count of rapid transit stations (2000-2010) 5) Years since station opened
Socioeconomic	
1) % of employees in professional occupations 2) % of employees in manufacturing industry 3) % of college-educated residents 4) unemployment rate 5) % of white residents 6) Capital accumulation (total housing unit change 2000-2010, debt-to-income ratio in 2010)	1) unemployment rate (omitted due to its multicollinearity with the poverty indicators) 2) % of residents below poverty level 3) % of employees in professional occupations 4) % of employees in manufacturing industry 5) % of college-educated residents 6) % of white residents 7) % of female residents 8) % of families with no children

First, for the MSA characteristics, previous empirical studies of TIG have indicated that the probability of TIG may differ across metropolitan areas or cities (e.g., Padeiro et al., 2019; Tehrani et al., 2019). Therefore, the relevant MSA characteristics need to be included in the examinations for their impact on the probability of TIG. In this dissertation, the MSA characteristics viewed as relevant include the physical and population sizes, the overall transit infrastructure development, as well as the socioeconomic characteristics. To be more specific, an MSA with larger land area may add the difficulties for residents of their commuting between the suburban and downtown, which may make the commuting easier by automobile than public transit. However, usually an MSA with larger land area would have large population size, and traffic congestion could become one of the barriers for commuting by auto, and could attract residents to use public transit, and thus increasing probability of TIG. In addition, the MSAs with better overall transit infrastructure will add to the attractiveness of the new transit to residents, and thus increase the probability of TIG. Moreover, the overall socioeconomic characteristics, such as the industrial and occupational compositions of employees, the overall unemployment rate, as well as the racial composition could affect probability of TIG.

Traditional gentrification theories raised by Marxian from the supply-side suggest that gentrification is triggered by the capital accumulation (Revington, 2015). Theoretically, surplus capital could be invested in building new dwellings or in refurbishing the old dwellings, thereby increasing the probability of TIG. To examine the impact of capital accumulation, two indicators—total housing unit change between 2000 and 2010 and the debt-to-income ratio in 2010 (i.e., the level in 2010 indicates the level after the opening of stations)—are included in the examinations to represent the level of capital accumulation. A higher increase in the total housing units and a smaller debt-to-income ratio are assumed to indicate more capital accumulation, and then raise the probability of TIG.

Second, one of the previous TIG studies (Brown, 2017) has briefly explored the neighborhood characteristics that could affect the probability of gentrification in Los Angeles. These characteristics include housing (median home value, median rent, and proportion of renter-occupied housing units) and socioeconomic (race, education, and household income) characteristics in the neighborhoods. In this dissertation, both the physical and socioeconomic characteristics of the CBGs are examined for their impact on TIG occurrence.

The location indicators of CBGs, including the distance to the nearest Central Business District (CBD) and the distance to the nearest freeway entrance are included in the examinations. Gentrification is usually presumed to happen in the inner city according to the previous theories due to the better accessibility to job opportunities (Location Theory under neoclassical economic framework) and the larger gap between potential ground rent and the current capitalized ground rent (Rent Gap Theory under Marxism framework) (Chava et al., 2019). Therefore, proximity to

CBD could be associated with higher probability of TIG. The distance to the nearest freeway entrance is the indicator of auto accessibility and also may affect the probability of TIG, but the direction of the effect is unclear. The higher auto accessibility could make living in the neighborhood more attractive (i.e., increase the probability of TIG) based on the Location Theory, but will simultaneously reduce the use of public transit, thus reducing the probability of TIG.

Previous studies argue that gentrification may only cause the influx of more affluent residents and the increase of residence density, instead of the displacement of residents prior to gentrification (e.g., Padeiro et al., 2019). Therefore, the housing density prior to the open of rapid transit stations could determine whether the CBG has space for more housing units, and may affect the probability of TIG. However, the direction of the effect is unclear. In addition, as shown in Chapter 3, rail transit has more evidence of inducing gentrification than BRT. Therefore, a dummy variable indicating the mode of the new transit station (i.e., 1 if the CBG is newly served by rail transit station) is also included to examine whether that is true when controlling for other factors. Moreover, some CBGs, especially in the downtown areas, are usually served by multiple rapid transit stations due to the higher density of these rapid transit stations. The higher density of stations usually offers better transit service and thus increase the probability of TIG. Additionally, the rapid transit stations in this study include all that are opened from 2000 through 2009, but the before-and-after impact in the TIG definition uses the changes between 2000 and 2010—at least one year after the station opening, which means the posttest could examine the different stage of change after the open of rapid transit stations. Therefore, the years since the station opened in 2010 is also included in the regression models.

In addition to the physical characteristics, the socioeconomic characteristics of the CBGs may also affect the probability of TIG. For example, the families with no children may be more likely to live in the transit-served areas because they have no concerns over school districts and commuting. Other factors such as the industrial and occupational compositions of employees, racial and gender composition, and the education and income levels before the rapid transit station opening could also affect the probability of TIG.

4.4.2 Methods for hypotheses examinations

Two-level hierarchical logistic regression models are estimated to examine the impact of the MSA-level and CBG-level characteristics on the probability of TIG. This approach is used to control for the potential effects of different variances across MSAs. The dependent variable is the binary variable that indicates the occurrence of TIG in the rapid-transit-served (RTS) neighborhoods (CBGs here) that are gentrifiable. The same models are estimated, respectively, using each of the definition of TIG presented in Section 4.2. The independent variables are listed in Table 15. To exclude the potential endogeneity that could be caused by the open of the rapid transit stations, the socioeconomic variables use their levels in 2000, the year that before (or at) the year when the rapid transit stations opened. In addition, to verify whether the different variances across MSAs will affect the regression results in the hieratical modeling, the simple logistic regression are also estimated for comparison.

Because TIG only refers to the upgrading in gentrifiable neighborhoods, the non-gentrifiable CBGs are not included in the set of observations for the regression models. Therefore, in total 692 gentrifiable CBGs out of the 1513 CBGs newly served by rapid transit stations are used as the set of observations for the hypotheses examinations. In addition, because that the RTS CBGs are all non-gentrifiable CBGs in four[4] out of the 40 MSAs with rapid transit stations opened from 2000 through 2009, only the other 36 MSAs are included in the study area.

In addition, the comparisons in Chapter 3 and Section 4.3 in this Chapter 4 generally show similar patterns of TIG between the short-term (i.e., 2000 – 2010) and long-term (i.e., 2000 – 2016) analyses, even though long-term analysis gives stronger evidence (in Chapter 3) and higher percentages (in Section 4.3) among CBGs in the treatment group. Therefore, here, the hypotheses examinations of the effects of MSA and neighborhood characteristics are only conducted for the TIG occurrence in the short-term (i.e., 2000 – 2010).

4.4.3 Description of dependent and independent variables

Dependent Variables

As shown in Table 16, the dependent variables show substantial variation across the MSAs and among all rapid-transit-served (RTS) CBGs for all the three definitions of the TIG occurrence. The mean probability of TIG are about 62% for Definition 1—the two-criterion definition, 41% for Definition 2—the three-criterion definition, and 38% for Definition 3—the significance-criterion definition, and the standard deviations are about 49% for all the three definitions.

[4] These four MSAs are Atlanta-Sandy Springs-Marietta, GA Metro Area; New Haven-Milford, CT Metro Area; Oxnard-Thousand Oaks-Ventura, CA Metro Area; and Worcester, MA Metro Area.

Independent Variables

Metropolitan area characteristics

For the independent variables (Table 16), the populations of the 36 MSAs range from about 0.13 million (Santa Fe, NM Metro Area) to 18 million (New York-Northern New Jersey-Long Island, NY-NJ-PA Metro Area), and the land areas range from 225 square miles (Trenton-Ewing, NJ Metro Area) to 14,566 (Phoenix-Mesa-Glendale, AZ Metro Area) square miles, suggesting high variation of the MSA size. The mean count of rapid transit stations until 2010 is 121 per MSA, indicating the average rapid transit service in the 36 MSAs are generally good. However, the standard deviation of the count of rapid transit stations until 2010 is 189, indicating of the service levels of rapid transit service among the 36 metropolitan areas are highly unbalanced. This imbalance can also been seen from the minimum and maximum counts of stations, which are 1 and 935, respectively. There is only one newly constructed commuter rail station opened in 2003 in Barnstable Town, MA Metro Area, which connecting to other commuter rail stations in the Greater Boston metropolitan area. In contrast, there are 935 rapid transit stations until 2010 in New York-Northern New Jersey-Long Island, NY-NJ-PA Metro Area. In addition, twenty-three (23) of the 36 MSAs had rapid transit service before 2000.

For the sociodemographic characteristics, the variation among the 36 MSAs is also large (Table 16). There are on average 36.5% of employees in professional occupations in the 36 MSAs, with the highest percentage being 49.1% (Washington-Arlington-Alexandria, DC-VA-MD-WV Metro Area) and the lowest being 24.4% (Las Vegas-Paradise, NV Metro Area). The average proportion of employees in manufacturing industry is 11.6%, and the highest proportion reaches to 27.1% (San Jose-Sunnyvale-Santa Clara, CA Metro Area), whereas the lowest is only 3.7% (Las Vegas-Paradise, NV Metro Area), suggesting different industrial structures across the 36 MSAs. In addition, the average proportion of residents (aged 25 or over) with college education is 28.8%, which is higher than the average level in the U.S. in 2000 (24.4%). Five MSAs have a proportion of residents with college education higher than 35%: Washington-Arlington-Alexandria, DC-VA-MD-WV Metro Area (42.5%), San Jose-Sunnyvale-Santa Clara, CA Metro Area (39.8%), San Francisco-Oakland-Fremont, CA Metro Area (38.8%), Boston-Cambridge-Quincy, MA-NH Metro Area (37.0%), and Santa Fe, NM Metro Area (36.9%) in 2000, not all of which are large MSAs. The average unemployment rate in 2000 is 5.4%, ranging from 3.5% (Minneapolis-St. Paul-Bloomington, MN-WI Metro Area) to 7.5% (Los Angeles-Long Beach-Santa Ana, CA Metro Area and Trenton-Ewing, NJ Metro Area). The 40 MSAs also vary greatly in their racial composition, with their proportions of white residents ranging from 52% (Los Angeles-Long Beach-Santa Ana, CA Metro Area) to 96% (Portland-South Portland-Biddeford, ME Metro Area).

Two indicators of the capital accumulation level—total housing unit change between 2000 and 2010 and debt-to-income ratio in 2010—are also examined for their impact on the probability of TIG. For total housing unit changes, the average rate of increase across all the 36 MSAs is 16%, with the standard deviation of 10.5%. The New Orleans-Metairie-Kenner, LA Metro Area had a decrease of 1.9% in the total housing units; this could result from the *Hurricane Katrina*. All the other 35 MSAs experienced increases in the total housing units during the decade, with the rate of increase ranging from 2.2% to 50%. Eleven MSAs had increases in total housing units over 20% during the decade, and the rate of increase in Las Vegas-Paradise, NV Metro Area was 50.1%. In contrast, 12 MSAs had their increases in total housing units below 10%, and the increase rate in Pittsburgh, PA Metro Area was only 2.2%. The mean debt-to-income ratio is 1.94 in 2010, with the minimum as 0.51 (Trenton-Ewing, NJ Metro Area) and the maximum as 2.57 (in eleven MSAs[5]). These two indicators suggest that the levels of capital accumulation are also heterogeneous among the MSAs.

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[5] These eleven MSAs include: Barnstable Town, MA Metro Area; Las Vegas-Paradise, NV Metro Area; Phoenix-Mesa-Glendale, AZ Metro Area; Eugene-Springfield, OR Metro Area; Los Angeles-Long Beach-Santa Ana, CA Metro Area; San Francisco-Oakland-Fremont, CA Metro Area; Sacramento--Arden-Arcade--Roseville, CA Metro Area; Ogden-Clearfield, UT Metro Area; Santa Fe, NM Metro Area; San Diego-Carlsbad-San Marcos, CA Metro Area; and Miami-Fort Lauderdale-Pompano Beach, FL Metro Area.

Table 16 Description of Dependent and Independent Variables

Variables	Obs	Mean	Std. Dev.	Min	Max
Dependent Variables (TIG Occurrence)					
Definition 1	692	0.6228	0.4850	0	1
Definition 2	692	0.4118	0.4925	0	1
Definition 3	692	0.3815	0.4861	0	1
Independent Variables					
Metropolitan Area Characteristics					
Physical					
Size					
Total population (2000)	36	3,146,739	3,646,673	129,292	18,323,062
Land areas (square miles)	36	5,122.59	3,075.18	224.56	14,565.75
Transit infrastructure					
# of rapid transit stations (2010)	36	120.72	189.27	1	935
Existence of prior rapid transit (= 1)	36	0.6389	0.4871	0	1
Socioeconomic					
% of professional (2000)	36	36.46%	4.80%	24.40%	49.07%
% of manufacturing (2000)	36	11.64%	4.62%	3.68%	27.11%
% of college-educated (2000)	36	28.79%	5.55%	17.33%	42.49%
% of unemployed (2000)	36	5.40%	1.04%	3.50%	7.51%
% of white (2000)	36	74.76%	11.50%	52.42%	96.49%
Total housing unit changes rates (00–10)	36	0.1616	0.1049	-0.0189	0.5012
Debt-to-income ratio (2010)	35	1.936286	0.546212	0.51	2.57
Census Block Group Characteristics					
Physical					
Distance to CBD (miles)	692	6.0450	6.2926	0.0694	50.2164
Distance to nearest freeway entrance (miles)	692	1.1315	1.6322	0.0149	22.1780
Housing density (2000)	692	5808	7673	4.8345	84284
New transit modes (Rail = 1)	692	0.8020	0.3988	0	1
Years since station opened	692	5.0968	3.0033	1	10
# of new rapid transit stations (00–09)	692	1.0751	0.3093	1	4
Socioeconomic (in 2000)					
% of poverty (2000)	692	24.56%	13.59%	0.00%	74.70%
% of professional (2000)	692	22.86%	11.99%	2.09%	77.54%
% of manufacturing (2000)	692	12.88%	8.55%	0.00%	53.52%
% of college-educated (2000)	692	14.90%	12.39%	0.00%	80.33%
% of white (2000)	692	46.18%	27.36%	0.22%	98.12%
% of female (2000)	692	50.31%	4.87%	13.62%	66.67%
% of families with no children	692	47.46%	11.76%	0.00%	100.00%

Neighborhood (Census block group) characteristics

The neighborhood characteristics are also examined for their impact on the occurrence of TIG, including both physical and socioeconomic characteristics. The physical characteristics include the location of each CBG in relation to the central business district (CBD) and its transportation service level. As shown in Table 16, the mean distance to the nearest CBD[6] of rail-transit-served (RTS) CBGs is 6.05 miles, but high variation exists, with the minimum distance being 0.07 mile, and the maximum being 50.22 miles, suggesting that the new rapid transit stations have served both the urban core and the suburban neighborhoods. The auto-accessibility also varies among the RTS CBGs, with the range of distance to the nearest freeway entrance from 0.01 mile to 22.2 miles. The range of housing density within the RTS CBGs are extremely high, from 4.8 to 84,284 housing units per square mile. Not surprisingly, the neighborhoods with the highest density are located in in New York-Northern New Jersey-Long Island, NY-NJ-PA Metro Area. In addition, the rapid transit stations are not evenly distributed, with 44 CBGs (6.4% of the 692 RTS CBGs) newly served by multiple rapid transit stations opened from 2000 through 2009. For example, in Philadelphia-Camden-Wilmington, PA-NJ-DE-MD Metro Area, one gentrifiable CBG is newly served by four rapid transit stations from 2000 through 2009.

The socioeconomic characteristics of neighborhoods before the rapid transit stations opened are also included in the examination for their impact on the probability of TIG. The average proportion of residents below poverty level in 2000 in the RTS CBGs is 24.6%, much higher than the average level in the U.S.—11.3%, and the maximum proportion is 74.7%, suggesting that the gentrifiable RTS neighborhoods generally are among the poor neighborhoods across the nation. This fact matches one of the tasks of rapid transit—to offer stable and rapid transit service to transit-dependents, most of whom are low-income (e.g., Padeiro et al., 2019), and this fact could increase the vulnerability of the residents in the neighborhoods with regard to being displaced by newcomers during the gentrification. In addition, this fact also suggests the potential endogeneity issues caused by the design of rapid transit, which may prefer the poor neighborhoods that are more likely to be gentrified. The average proportion of residents in professional occupations is 22.9%, with the maximum as high as 77.5% and the minimum proportion as low as 2.1%. The average proportion of residents with college education (among aged 25 and over) is 14.9%, which is much lower than the average proportion of the 36 MSAs (28.8%), and much lower than the

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[6] The CBDs are defined as the location of City Hall in each city of the 40 MSAs if the City Hall locates within the CBD zone, and are adjusted if the City Hall is not within the CBD zone.

average proportion in the U.S. in 2000 (24.4%). However, the proportion of residents with college education highly varies among the RTS CBGs, with the maximum proportion as high as 80.3% and the minimum proportion as low as 0%. These three indicators (proportion of residents below poverty level, proportion of residents in professional occupations, and proportion of residents with college education) reflect the substantial variation of socioeconomic status among the RTS CBGs that are gentrifiable. In addition, gentrification studies have argued that the working class, most of whom work in manufacturing, are among the most vulnerable during the gentrification. Therefore, the proportion of employees in manufacturing industry before the station opened is also included. The average proportion of manufacturing workers in all gentrifiable RTS CBGs is 12.9%, which is lower than the average proportion in the U.S.—14.4%[7] in 2000, but the maximum is 53.5%, suggesting that some gentrifiable CBGs in the RTS areas are the agglomeration areas of manufacturing workers/industry. Moreover, the proportion of white residents is also included in the model, with its mean being 46.2%, much lower than the average proportion in U.S.—75.1% and suggesting that these gentrifiable neighborhoods newly served by rapid transit stations have disproportionately more minority residents. In addition, compared to other variables, the proportion of white residents has the most extreme distribution in those gentrifiable RTS CBGs, with the lowest proportion being 0.22%, and the highest being 98.1%, suggesting a high variation in racial composition among those CBGs, which could be partly result from housing segregation that is closely associated with the structural racism in the U.S. The average proportion of female residents is about 50.3%, but still variation exists among those gentrifiable RTS CBGs, ranging from 13.6% to 66.7%. Moreover, gentrification studies have also argued that households with no children would more likely be the newcomers of the RTS neighborhoods, because they have less concern over the school districts and children' daily commuting. To test that argument, the proportion of the families with no children under 18 years old is also included in the models. In the gentrifiable RTS CBGs, the average proportion of families with no children is about 47.5% before the station opened, with the standard deviation being 11.8%, suggesting about half of the families do not have children before the station opened.

4.4.4 Results of hypotheses examination

To verify the stability of the impacts, the MSA characteristics and CBG characteristics are first examined in separate regression models for their impact on the probability of Transit-Induced Gentrification (TIG), and then are examined in the same regression models. To each of the three

[7] Data Source: https://fred.stlouisfed.org/series/USAPEFANA

regression models, two regression methods are applied: the normal logistic regression and the two-level hierarchical logistic regression (HLR) that controls for the different variances across MSAs. These six regression models are applied to all the three definitions of the occurrence of TIG (1 if occurred, and 0 if not), respectively, which means there are in total 18 regression models. The results are informative and generally consistent across the models for CBG characteristics, but are inconsistent across models with different definitions of TIG occurrence (i.e., the dependent variable) for MSA characteristics (Table 17).

Dependent variable: TIG occurrence defined by Definition 1 (Two-criterion definition)

The six models are generally consistent in the significance of both MSA and CBG characteristics for their impact on the probability of TIG (Table 17). For MSA characteristics, none of the four physical characteristics shows significant impacts on the probability of TIG for all the four models (i.e., Models 1, 2, 5, & 6). For the socioeconomic characteristics of MSAs, only the HLR model including both MSA and CBG characteristics (i.e., Model 6) shows that a higher proportion of residents in professional occupations in the MSA raises the probability of TIG. Both the higher proportion of employees in manufacturing industry and the higher unemployment rate significantly reduce the probability of TIG, when the models only include MSA characteristics (i.e., Models 1 & 2), but this significance disappears when adding CBG characteristics to the models (i.e., Models 5 & 6).. The proportion of residents with college education at the MSA-level suggests a significant negative impact in the two models only including MSA characteristics and the HLR model including both MSA and CBG characteristics and controlling for the variances across MSAs (i.e., Models 1, 2 & 6). The proportion of white residents at the MSA-level does not show any significant impact on the probability of TIG across all the four models (i.e., Models 1, 2, 5, & 6).

With regard to the capital accumulation level in the MSAs, the total housing unit change between 2000 and 2010, does not suggest a significant impact on the probability of TIG for all the four models (i.e., Models 1, 2, 5, & 6). In contrast, the debt-to-income ratio in 2010 suggests a significant positive impact in the two models including both MSA and CBG characteristics (i.e., Models 5, & 6).

For the CBG characteristics, the new station density around CBG (i.e., the count of new rapid transit stations opened from 2000 through 2009 that are accessible by half-mile walk from the CBG) suggests a significant negative impact on the probability of TIG in both the HLR models controlling for the variances across the MSAs (i.e., Model 4 & 6). Other physical characteristics do not suggest significant effects. In the regression models, the gentrifiable CBGs served by rail transit do not show significant high probability of TIG than those served by BRT.

The socioeconomic variables of CBGs generally have consistent conclusions across the four models (i.e., Models 3, 4, 5, & 6). The proportion of residents below poverty level and the proportion of families with no children have significant positive impacts, and the proportion of employees in manufacturing industry and the proportion of female residents have significant negative impacts on the probability of TIG.

In sum, when using TIG occurrence defined by Definition 1, a two-criterion definition, as the dependent variable, none of the four physical characteristics, indicating the sizes of the MSA and transit service levels in the MSA, shows significant impacts on the probability of TIG. However, some MSA socioeconomic characteristics do have significant effects, but the effects are not stable across models. In the HLR model with both MSA and CBG characteristics included, the proportions of residents in professional occupations and of residents with college educations at the MSA-level show significant impacts. In addition, the models suggest a positive impact of one indicator of capital accumulation—the debt-to-income ratio, which means a higher debt-to-income ratio (suggesting a lower capital accumulation level) in the MSA raises the probability of TIG. This result is not consistent with the hypothesis of TIG raised based on Marxism framework, saying that the capital accumulation causes gentrification from the supply side, whereas transit is the trigger of the process. Moreover, the models only show significant impact of the housing density among the physical characteristics of gentrifiable CBGs, and gentrifiable CBGs served by rail transit do not show significant difference from the gentrifiable CBGs served by BRT in the probability of TIG. Some socioeconomic characteristics of the gentrifiable CBGs such as the proportion of residents below poverty level, the proportion of employees in manufacturing industry, the proportion of female residents, and the proportion of families with no children have consistently significant impact on the probability of TIG.

Table 17 Regression Results of Factors Affect the Occurrence of Transit-Induced Gentrification

Variables **Report Marginal effects (P-values)**	**Definition 1: Two-criterion definition**					
	MSA-level		**CBG-level**		**MSA & CBG**	
Regression methods	Logit Model 1	HLR Model 2	Logit Model 3	HLR Model 4	Logit Model 5	HLR Model 6
MSA						
Physical						
Size						
Total population (billion)	-4.4111 (0.5877)	-4.4112 (0.5109)			-1.1787 (0.9145)	-1.1787 (0.8635)
Land areas (billion miles)	-0.0033 (0.8011)	-0.0033 (0.6779)			-0.0005 (0.9602)	-0.0005 (0.9498)
Transit Infrastructures						
Total rapid transit stations (thousand)	0.0214 (0.8869)	0.0214 (0.8707)			-0.0236 (0.8939)	-0.0236 (0.8520)
Existence of prior rapid transit	0.0295 (0.5866)	0.0295 (0.5309)			-0.0013 (0.9863)	-0.0013 (0.9840)
Socioeconomic						
% of professional	1.8957 (0.3834)	1.8956 (0.2418)			2.9741 (0.2356)	**2.9741*** (0.0669)
% of manufacturing	**-1.1956**** (0.0320)	**-1.1955***** (0.0040)			-0.5984 (0.3992)	-0.5984 (0.1360)
% of college educated	**-3.2754*** (0.0638)	**-3.2751**** (0.0313)			-3.1800 (0.1197)	**-3.1800**** (0.0272)
% of unemployed	**-9.2903**** (0.0419)	**-9.2894**** (0.0170)			-5.5749 (0.2569)	-5.5749 (0.1831)
% of white	-0.3687 (0.2749)	-0.3687 (0.2486)			-0.1580 (0.7052)	-0.1580 (0.6541)
Capital Accumulation						
Total housing unit changes (00–10)	-0.2506 (0.5793)	-0.2506 (0.3016)			-0.3829 (0.3331)	-0.3829 (0.1303)
Debt-to-income ratio	0.0784 (0.1044)	0.0784 (0.1013)			**0.1240**** (0.0270)	**0.1240***** (0.0067)

* p-value < 0.1, ** p-value < 0.05, *** p-value <0.01

Table 17 Regression Results of Factors Affect the Occurrence of Transit-Induced Gentrification (Continued)

Variables **Report Marginal effects (P-values)**	**Definition 1: Two-criterion definition**					
	MSA-level		**CBG-level**		**MSA & CBG**	
Regression methods	Logit Model 1	HLR Model 2	Logit Model 3	HLR Model 4	Logit Model 5	HLR Model 6
Census Block Group						
Physical						
Distance to CBD (thousand miles)			-0.0251 (0.9947)	-0.4937 (0.8784)	-0.6600 (0.8446)	-0.6600 (0.8152)
Distance to freeway (thousand miles)			-11.2434 (0.5726)	-10.7558 (0.3046)	-6.9169 (0.7840)	-6.9169 (0.7821)
Housing density (thousand / mile^2) (2000)			-0.0008 (0.7844)	-0.0001 (0.9685)	0.0016 (0.5897)	0.0016 (0.2902)
New transit modes (Rail = 1)			0.0696 (0.3105)	0.0762 (0.2501)	0.0722 (0.1676)	0.0722 (0.3111)
Years since station opened			-0.0026 (0.7390)	-0.0014 (0.8770)	0.0027 (0.7483)	0.0027 (0.7285)
New station density (2000-2009)			-0.1019 (0.1994)	**-0.1036**** (0.0257)	-0.0976 (0.1472)	**-0.0976**** (0.0329)
Socioeconomic (in 2000)						
% of poverty			**0.6092***** (0.0004)	**0.5883***** (0.0000)	**0.5461***** (0.0028)	**0.5461***** (0.0001)
% of professional			-0.0173 (0.9491)	-0.0302 (0.9051)	-0.1312 (0.5750)	-0.1312 (0.6330)
% of manufacturing			**-0.4967**** (0.0359)	**-0.5182**** (0.0339)	**-0.4800*** (0.0981)	**-0.4800*** (0.0560)
% of college educated			0.0897 (0.7371)	0.0910 (0.6684)	0.1581 (0.4896)	0.1581 (0.4888)
% of white			0.0182 (0.8354)	0.0240 (0.7968)	0.0476 (0.6803)	0.0476 (0.6196)
% of female			**-1.0354**** (0.0217)	**-0.9924**** (0.0108)	**-0.9927*** (0.0533)	**-0.9927**** (0.0132)
% of families with no children			**0.4108**** (0.0402)	**0.4262***** (0.0092)	**0.4979***** (0.0030)	**0.4979***** (0.0097)

* p-value < 0.1, ** p-value < 0.05, *** p-value <0.01

Table 17 Regression Results of Factors Affect the Occurrence of Transit-Induced Gentrification (Continued)

Variables **Report Marginal effects (P-values)**	**Definition 2: Three-criterion definition**					
	MSA-level		**CBG-level**		**MSA & CBG**	
Regression methods	Logit Model 7	HLR Model 8	Logit Model 9	HLR Model 10	Logit Model 11	HLR Model 12
MSA						
Physical						
Size						
Total population (billion)	-1.0958 (0.8980)	-1.0955 (0.8662)			3.4140 (0.7357)	3.4140 (0.5873)
Land areas (billion miles)	0.0011 (0.9051)	0.0011 (0.8860)			0.0061 (0.6223)	0.0061 (0.3073)
Transit Infrastructures						
Total rapid transit stations (thousand)	0.0110 (0.9426)	0.0110 (0.9365)			-0.0266 (0.8895)	-0.0266 (0.8406)
Existence of prior rapid transit	-0.0185 (0.7670)	-0.0185 (0.7149)			-0.0674 (0.3113)	-0.0674 (0.1485)
Socioeconomic						
% of professional	1.8616 (0.3668)	1.8616 (0.2522)			2.3976 (0.2073)	2.3976 (0.1140)
% of manufacturing	-0.2280 (0.6150)	-0.2280 (0.5869)			0.0793 (0.9064)	0.0793 (0.8269)
% of college educated	-2.6464 (0.1750)	**-2.6464*** (0.0754)			-2.2125 (0.1764)	**-2.2125*** (0.0783)
% of unemployed	**-9.0936*** (0.0518)	**-9.0936***** (0.0064)			-4.1688 (0.2457)	-4.1688 (0.1001)
% of white	-0.1977 (0.5223)	-0.1977 (0.4672)			0.1610 (0.5661)	0.1610 (0.5600)
Capital Accumulation						
Total housing unit changes (00–10)	-0.3124 (0.4470)	-0.3124 (0.2223)			-0.5301 (0.1983)	**-0.5301***** (0.0078)
Debt-to-income ratio	0.0878 (0.1520)	**0.0878**** (0.0447)			**0.1288**** (0.0195)	**0.1288***** (0.0001)

* p-value < 0.1, ** p-value < 0.05, *** p-value <0.01

Table 17 Regression Results of Factors Affect the Occurrence of Transit-Induced Gentrification (Continued)

Variables Report Marginal effects (P-values)	Definition 2: Three-criterion definition					
	MSA-level		CBG-level		MSA & CBG	
Regression methods	Logit Model 7	HLR Model 8	Logit Model 9	HLR Model 10	Logit Model 11	HLR Model 12
Census Block Group						
Physical						
Distance to CBD (thousand miles)			0.8748 (0.7822)	0.8752 (0.7323)	1.1845 (0.7202)	1.1845 (0.6511)
Distance to freeway (thousand miles)			-16.1832 (0.4528)	-16.1821 (0.2494)	-33.9907 (0.1365)	**-33.9907**** (0.0426)
Housing density (thousand / mile^2) (2000)			-0.0063 (0.1016)	**-0.0063***** (0.0088)	-0.0049 (0.3007)	-0.0049 (0.2903)
New transit modes (Rail = 1)			**0.1150*** (0.0575)	**0.1150**** (0.0177)	**0.1208*** (0.0712)	**0.1208**** (0.0235)
Years since station opened			-0.0050 (0.4538)	-0.0050 (0.5515)	0.0006 (0.9367)	0.0006 (0.9357)
New station density (2000-2009)			-0.0222 (0.7269)	-0.0222 (0.6992)	-0.0214 (0.7290)	-0.0214 (0.7195)
Socioeconomic (in 2000)						
% of poverty			**0.3806**** (0.0383)	**0.3806***** (0.0065)	**0.3199*** (0.0839)	**0.3199**** (0.0342)
% of professional			0.2709 (0.3438)	0.2708 (0.3825)	0.1574 (0.5959)	0.1574 (0.6153)
% of manufacturing			-0.0458 (0.8516)	-0.0457 (0.8327)	-0.1719 (0.5802)	-0.1719 (0.4485)
% of college educated			0.0665 (0.8210)	0.0665 (0.7911)	0.0970 (0.7130)	0.0970 (0.7012)
% of white			-0.0696 (0.4614)	-0.0696 (0.4867)	-0.0776 (0.5178)	-0.0776 (0.4813)
% of female			-0.4668 (0.2782)	-0.4668 (0.2944)	-0.4615 (0.4233)	-0.4615 (0.2560)
% of families with no children			**0.5161**** (0.0196)	**0.5161***** (0.0034)	**0.5816***** (0.0019)	**0.5816***** (0.0032)

* p-value < 0.1, ** p-value < 0.05, *** p-value <0.01

Table 17 Regression Results of Factors Affect the Occurrence of Transit-Induced Gentrification (Continued)

Variables **Report Marginal effects (P-values)**	**Definition 3: Significance-criterion definition**					
	MSA-level		**CBG-level**		**MSA & CBG**	
Regression methods	Logit Model 13	HLR Model 14	Logit Model 15	HLR Model 16	Logit Model 17	HLR Model 18
MSA						
Physical						
Size						
Total population (billion)	-9.1721 (0.2792)	-9.1720 (0.2035)			-7.7565 (0.3713)	-7.7565 (0.1796)
Land areas (billion miles)	**-0.0185**** (0.0388)	**-0.0185**** (0.0126)			**-0.0150*** (0.0821)	**-0.0150**** (0.0174)
Transit Infrastructures						
Total rapid transit stations (thousand)	0.1381 (0.2936)	0.1381 (0.3866)			0.1037 (0.4298)	0.1037 (0.4760)
Existence of prior rapid transit	0.0754 (0.1519)	0.0754 (0.1841)			0.0556 (0.3413)	0.0556 (0.2582)
Socioeconomic						
% of professional	**-4.1312**** (0.0315)	**-4.1312***** (0.0092)			**-3.5563*** (0.0741)	**-3.5563**** (0.0195)
% of manufacturing	**-1.0735*** (0.0626)	**-1.0735***** (0.0064)			-0.4608 (0.4921)	-0.4608 (0.2989)
% of college educated	0.4169 (0.8069)	0.4169 (0.7798)			1.1283 (0.4958)	1.1283 (0.4071)
% of unemployed	**-12.1830***** (0.0009)	**-12.1830***** (0.0035)			**-6.2718*** (0.0595)	-6.2718 (0.1283)
% of white	**-1.2083***** (0.0001)	**-1.2083***** (0.0000)			**-0.8131***** (0.0038)	**-0.8131***** (0.0019)
Capital Accumulation						
Total housing unit changes (00–10)	0.0994 (0.7329)	0.0994 (0.7261)			0.0250 (0.9480)	0.0250 (0.9257)
Debt-to-income ratio	-0.0065 (0.8879)	-0.0065 (0.9050)			0.0518 (0.2637)	0.0518 (0.3209)

* p-value < 0.1, ** p-value < 0.05, *** p-value <0.01

Table 17 Regression Results of Factors Affect the Occurrence of Transit-Induced Gentrification (Continued)

Variables **Report Marginal effects (P-values)**	**Definition 3: Significance-criterion definition**					
	MSA-level		**CBG-level**		**MSA & CBG**	
Regression methods	Logit Model 13	Logit Model 13	Logit Model 13	Logit Model 13	Logit Model 13	Logit Model 13
Census Block Group						
Physical						
Distance to CBD (thousand miles)			-1.5273 (0.6732)	-1.5268 (0.7362)	-2.3690 (0.4716)	-2.3690 (0.5735)
Distance to freeway (thousand miles)			-24.8502 (0.1527)	-24.8342 (0.1874)	-12.6665 (0.6121)	-12.6665 (0.5280)
Housing density (thousand / $mile^2$) (2000)			-0.0019 (0.5002)	-0.0019 (0.3204)	0.0002 (0.9503)	0.0002 (0.9322)
New transit modes (Rail = 1)			0.0636 (0.2717)	0.0636 (0.3704)	0.0545 (0.3300)	0.0545 (0.4229)
Years since station opened			0.0020 (0.7763)	0.0020 (0.8233)	0.0079 (0.4263)	0.0079 (0.3987)
New station density (2000-2009)			0.0018 (0.9726)	0.0018 (0.9745)	0.0023 (0.9676)	0.0023 (0.9674)
Socioeconomic (in 2000)						
% of poverty			**0.5544***** (0.0005)	**0.5544***** (0.0005)	**0.4962***** (0.0081)	**0.4962***** (0.0056)
% of professional			-0.1857 (0.4886)	-0.1857 (0.4531)	-0.1064 (0.7396)	-0.1064 (0.6729)
% of manufacturing			-0.3106 (0.2482)	-0.3105 (0.1248)	-0.2699 (0.3796)	-0.2699 (0.2097)
% of college educated			0.3954 (0.1061)	0.3953 (0.1274)	0.3599 (0.1787)	0.3599 (0.2036)
% of white			-0.1138 (0.2650)	-0.1138 (0.1463)	-0.0761 (0.4078)	-0.0761 (0.4263)
% of female			**-0.8950**** (0.0207)	**-0.8949**** (0.0250)	**-0.6999*** (0.0703)	**-0.6999**** (0.0479)
% of families with no children			**0.5390***** (0.0059)	**0.5390***** (0.0004)	**0.5067***** (0.0015)	**0.5067***** (0.0012)

* p-value < 0.1, ** p-value < 0.05, *** p-value <0.01

Dependent variable: TIG occurrence defined by Definition 2 (Three-criterion definition)

Models 7-12 show the regression results of MSA and CBG characteristics on the probability of TIG defined by Definition 2, the three-criterion definition. These regression results generally show fewer MSA characteristics have significant effects on the probability of TIG than models using the two-criterion definition of TIG occurrence (i.e., Definition 1) as the dependent variable. None of the physical characteristics of MSA, including the sizes of the MSA and the transit service levels of MSA, shows significant impacts on the probability of TIG for all the four models. For the socioeconomic characteristics, Models 8 and 12 show a significant negative impact of the proportion of residents with college education at the MSA-level, and Model 7 & 8, which only includes MSA characteristics, show a significant negative impact of the unemployment rate.

In addition, the two capital accumulation indicators—total housing unit change and debt-to-income ratio both show significant impacts in the HLR model including both MSA and CBG characteristics (Model 12). The impact of both of these indicators is inconsistent with the hypothesis, suggesting that the higher capital accumulation may not associated with higher probability of TIG.

Different from models using the two-criterion definition of TIG occurrence (i.e., Definition 1), the gentrifiable CBGs served by rail transit show significant higher probability of TIG than the gentrifiable CBGs served by BRT in all the four models (i.e., Models 9-12). Housing unit density of the CBGs also suggests a significant negative impact in Models 10, which include CBG characteristics only and controls for the variance across MSAs (i.e., HLR model). The distance to the freeway show a significant negative impact on the probability of TIG only in the HLR model including both MSA and CBG characteristics (i.e., Model 12).

Less socioeconomic characteristics of the gentrifiable CBGs in Models 9-12, using Definition 2 as the dependent variable, show consistent significance for their impacts on the probability of TIG, when comparing with Model 3-6, using Definition 1 as the dependent variable. Only the proportion of residents below poverty level and the proportion of families with no children show consistently significant positive impact on the probability of TIG.

In sum, the regression results using Definition 2, the three-criterion definition indicate the capital accumulation may not increase the probability of TIG. The sizes of the MSA and transit service levels in the MSA show no evidence of a significant impact. In the meantime, the proportion of residents with college education and the unemployment rate in the MSA show significant negative impacts. For the characteristics of CBGs, the rail-served CBGs show a significant higher probability of TIG than the BRT-served CBGs. In addition, the housing unit density and the distance to freeway show significant negative impacts in some models, but the significance is not stable. Among the socioeconomic characteristics of the CBGs, only two (proportion of residents below poverty level and proportion of families with no children) show consistent significant impacts, comparing to four in models using Definition 1, the two-criterion definition, as the dependent variable.

Dependent variable: TIG occurrence defined by Definition 3 (Significance-criterion definition)

When changing the dependent variable to the occurrence TIG defined by Definition 3, the significance-criterion definition, the MSA characteristics that show significant impacts on TIG are different from the models using the other two definitions of TIG. The MSA land area shows a consistent significant negative impact on the probability of TIG in all models (Model 13, 14, 17, & 18), but no significant impact has been found of the two indicators of the transit service levels in the MSAs. Among the socioeconomic characteristics of MSA, significant negative impacts are found for the proportion of residents in professional occupations, the proportion of employees in manufacturing industry (the models including MSA characteristics only), the unemployment rate (excluding the HLR model including both MSA and CBG characteristics), and proportion of white residents.

Neither of the two capital accumulation indicators in the MSA and none of the physical characteristics of CBGs shows significant impacts on the probability of TIG for all the four models (i.e., Models 13, 14, 17, & 18). This result indicates the gentrifiable CBGs served by rail transit also do not show a significant higher probability of TIG than those served by BRT.

Similar to the models using the other two definitions of TIG, some socioeconomic characteristics of CBGs using Definition 3 also show consistent results in significance in Models 15-18, such as the proportion of residents below poverty level, the proportion of female residents, and the proportion of families with no children. The directions of impacts of these three socioeconomic characteristics of CBGs are consistent with directions in models using the other two definitions of TIG.

In sum, when using the occurrence of TIG defined by Definition 3, the significance-criterion definition, as the dependent variable, the MSA land area shows a significant negative impact on the probability of TIG, but few other physical characteristics show consistent significant impacts. Some socioeconomic characteristics at MSA-level show significant negative impacts, including the proportion of residents in professional occupations, the proportion of employees in manufacturing industry, the unemployment rate, and the proportion of white residents, but only the proportion of residents in professional occupations and the proportion of white residents show consistent significance in their impacts across the four models (Models 13, 14, 17, & 18). None of the capital accumulation indicators and the physical characteristics of CBGs shows significant impacts for all the models. The regression results of the socioeconomic characteristics of the CBGs are generally consistent with the results using the other two definitions of TIG (i.e., the two-criterion definition and the three-criterion definition). The effects of the proportion of residents below poverty level, the proportion of female residents, and the proportion of families with no children suggest evidence of affecting the probability of TIG.

Comparisons of the results across the three definitions of TIG occurrence

The three sets of models generally show similar results for socioeconomic characteristics of CBGs, and some of the physical characteristics of CBGs such as the housing density. For MSA characteristics, however, these model results show greater variation and sometimes contradict with each other.

To be more specific, for MSA characteristics, when including both the MSA and CBG characteristics in the model together and controlling for the variances across different MSAs (i.e., the HLR models), the significance of independent variables varies across models models:

1. The land area of MSA only suggests a significant negative impact in Model 18 that uses Definition 3, the significance-criterion definition of TIG, as the dependent variable.
2. The proportion of residents in professional occupations show significant positive impacts in Model 6 that uses Definition 1, the two-criterion definition, but show significant negative impacts in Model 18 that uses Definition 3, the significance-criterion definition of TIG, as the dependent variable.
3. The proportion of residents with college education show significant negative impacts in Model 6 that uses Definition 1, the two-criterion definition, and Model 12 that uses Definition 2, the three-criterion definition, as the dependent variable.

4. The proportion of white residents only suggests significant negative impacts in Model 18, using Definition 3, the significance-criterion definition of TIG, as the dependent variable.
5. In addition, the two capital accumulation indicators suggest significant impacts on the probability of TIG, for both the models using Definition 1 and Definition 2, but not the model using Definition 3, as the dependent variable. The directions of the impact, however, are opposite to the directions suggested by the Marxian, meaning the capital accumulation is less likely to increase the probability of TIG.

Different from the MSA characteristics, the socioeconomic characteristics of CBGs show more consistency for the impact on the probability of TIG across the models. All the models show that the proportion of residents below the poverty level and proportion of families with no children could significantly increase the probability of TIG, regardless the definitions of TIG. The proportion of female residents shows a significant negative impact on the probability of TIG, when using Definition 1 and Definition 3, but not when using Definition 2. Meanwhile, the proportion of employees in manufacturing industry suggests a significant negative impact on the probability of TIG, when using Definition 1, but not when using Definition 2 and Definition 3.

The physical characteristics of CBGs almost show no consistency for the impact on the probability of TIG. For example, none of the physical characteristics of CBGs shows significant impacts when using Definition 3, the significance-criterion definition. The new station density around CBG (i.e., the count of new rapid transit stations opened from 2000 through 2009 that are accessible by half-mile walk from the CBG) suggest a significant negative impact when using Definition 1, the two-criterion definition; whereas the distance to freeway only shows a significant negative impact when using Definition 2, the three-criterion definition. In addition, only Definition 2 shows higher probability of TIG in gentrifiable CBGs served by rail transit than those served by BRT, which is consistent with the conclusions in Chapter 3.

The proportion of white residents at the CBG-level suggests few significant impacts on the probability of TIG, regardless of the definitions of TIG, but the proportion of white residents at the MSA-level suggests significant negative impacts when using Definition 3, the most stringent definition among the three, but not when using the other two definitions. These results suggest that vulnerability to TIG of MSAs with high proportions of people of color is sensitive to the definition of TIG, and different definitions could lead to different conclusions.

Comparisons of Models of TIG and TIU

In addition to the examinations of how factors (i.e., MSA and CBG characteristics) affect the probability of TIG in gentrifiable CBGs that are newly served by rapid transit stations, the examinations of the same factors are also applied to explore how these factors affect the probability of TIU in all CBG, regardless of the gentrifiability, that are newly served by rapid transit stations. The data description and regression results are presented in the two tables in the Appendix (Table 18 & Table 19). Basically, the examinations of how MSA and CBG characteristics affecting the probability of TIU give similar results with the models of TIG. The impacts of MSA characteristics show great variation across different definitions as do the impacts of physical characteristics of CBGs. In the meantime, the socioeconomic characteristics of CBGs show more consistency in their impacts on the probability of TIG. However, some detailed impacts are different between the impacts on TIG and on TIU.

4.4. Discussions and Conclusions

Previous studies have not simultaneously examined the metropolitan-level and neighborhood-level factors that may affect the probability of TIG. This chapter tries to fulfil this limitation within the literature by examining the impact of both MSA and CBG characteristics on the probability of TIG. Due to the arbitrariness of selecting the thresholds to define the occurrence of TIG, I use three different definitions to validate the hypothesis testing results. My hypotheses tests use the hieratical logistic regression (HLR) models to capture the different variances across MSAs, and compare the results with the normal logistic regression models.

Three different definitions are used to define the occurrence of TIG—the two-criterion definition, the three-criterion definition, and the significance-criterion definition. These three different definitions give about 60-70%, 40-50%, and 30-40% of gentrifiable treated CBGs that experienced TIG. In addition, the results over long-term are generally consistent with the results over short-term, and show higher percentages over long-term for both rail- and BRT-served CBGs than over short-term. For high-end BRT-served CBGs, the significance-criterion definition gives a higher percentage, the three-criterion definition gives the same percentage, and the two-criterion definition gives a lower percentage over long-term than over short-term.

Based on the three definitions of TIG, the MSA and CBG characteristics were examined for their impact on the probability of TIG, and the results are informative. First, the examinations show inconsistent results for MSA characteristics with respect to their impact on the probability of TIG. For the physical size of the MSA (i.e., land area), only models using the significance-criterion definition of TIG occurrence as the dependent variable suggest significant negative impacts on the probability of TIG. The socioeconomic characteristics of MSAs also show inconsistent results across models. For example, the proportion of white residents only shows a significant negative impact when using the significance-criterion definition of TIG. In addition, the capital accumulation in MSAs does not show evidence of increase the probability of TIG.

Different from the MSA characteristics, some socioeconomic characteristics of CBGs show consistent significance for their impact on the probability of TIG across the models. For example, consistent significant evidence has been found for the positive impact of the proportion of residents below the poverty level and proportion of families with no children, regardless of the definitions of TIG. In addition, some socioeconomic characteristics of CBGs show consistent significant impact on the probability of TIG across models using the same definition of TIG. To be more specific, the proportion of female residents suggests a significant negative impact under the two-criterion and the significance-criterion definitions, and the proportion of employees in manufacturing industry suggests a significant negative impact under the two-criterion definition.

Some physical characteristics of CBGs also show significant impacts on the probability of TIG. For example, the new station density around CBG (i.e., the count of new rapid transit stations opened from 2000 through 2009 that are accessible by half-mile walk from the CBG) shows some evidence of negative impact under the two-criterion definition of TIG, and the gentrifiable CBGs served by rail transit show some evidence of higher probability of TIG than those served by BRT under the three-criterion definition. The distance to freeway shows significant negative impacts under the three-criterion definition, suggesting a better auto-accessibility may not increase the probability of TIG. Other physical characteristics of CBGs in the models do not show significant impacts on the probability of TIG.

Some limitations exist for the examinations of influential factors to the probability of TIG. The independent variables (i.e., the MSA and CBG characteristics) could cover most of the potential factors that affect probability of TIG according to previous empirical and fundamental studies, but not all of them. For example, some policies such as the Transit-Oriented Development, housing policies, and anti-gentrification/displacement policies could also be influential to the probability of TIG. In addition, some invisible social factors of the neighborhoods could also be influential, such as the social capital and the level of local autonomy. Future efforts are still needed to examine these policy and social characteristics for their impacts on TIG.

The three definitions of the occurrence of TIG perform differently with respect to the percentages of gentrifiable CBGs experienced TIG and the factors affecting the probability of TIG. Use of the three-criterion definition indicates: (i) the gentrifiable CBGs served by rail transit have higher probability of TIG than those served by BRT over both the short- and long-term, and (ii) the gentrifiable CBGs served by high-end BRT have higher probability of TIG than those served by BRT but lower probability than those served by rail transit over the short-term and the lowest probability of all gentrifiable CBGs over the long-term. These two findings are consistent with similar findings in the examinations of TIG hypothesis in Chapter 3. Neither of the other two definitions (i.e., the two-criterion and the significance-criterion definitions) show that consistency with regard to the two findings above. Therefore, the three-criterion definition may be most appropriate for use by policy makers and planners. This three-criterion definition classifies almost half (40-50%) of RTS CBGs experiencing gentrification. With use of the three-criterion definition, factors significantly associated with TIG include the distance to freeway, the new transit mode (i.e., rail or BRT), and the CBG characteristics such as the proportions of residents below poverty level and of families with no children. A limitation of the three-criterion definition is that it may underestimate the probability of TIG (relative to use of the two-criterion definition) and neglect some factors that could affect the probability of TIG, such as the land area of the MSA, the proportion of white residents in the MSA, the proportions of female residents and of employees in manufacturing in the neighborhoods, and the new rapid transit station density around the neighborhood.

In addition to the recommendation of the definition/measure of TIG, the results in this study also have some policy implications. For example, knowing the influential factors could help policy makers and transit planners identifying the neighborhoods that have higher risks in the occurrence of TIG, and then assist them to better design the rapid transit lines, and to target the policies to the high-risk areas to reduce the effects of gentrification. To be more specific, the regression results suggest that neighborhoods with denser rapid transit stations around are less likely to experience TIG. Given this finding, transit planners may consider designing denser rapid transit stations when planning new rapid transit lines. In addition, the regressions suggest higher probability of TIG in neighborhoods with higher poverty rates. Residents below the poverty level are usually the major groups of the "displacee" during gentrification (Newman & Wyly, 2006). Therefore, suitable policies such as affordable housing and rent ceilings need to be targeted to these neighborhoods with high risks of gentrification. All regression models show that neighborhoods with higher proportions of families with no children are more likely to experience gentrification.

These results suggests transit planners to pay more attention to the neighborhoods with higher proportion of families with no children when planning rapid transit lines.

Previous studies have a debate on whether MSAs/neighborhoods with higher proportions of people of color are more likely to experience TIG. Some studies confirmed that MSAs/neighborhoods with higher proportions of people of color have a greater likelihood of TIG (e.g. Delmelle & Nillsson, 2020), but some found less likelihood (e.g. Pollack et al., 2010; Brown, 2016; Bardaka et al., 2018), and some found no significant association, positive or negative, between the proportion of people of color and the probability of TIG (e.g. Deka, 2017). This dissertation with three different binary measures of TIG mirrors the findings of previous mixed results, but only at the MSA-level and not at the neighborhood-level. To be more specific, these results show that the proportion of white residents at the neighborhood-level at the time of station-opening has no significant impacts on the probability of TIG, regardless the definitions of TIG. However, the proportion of white residents at the MSA-level has significant negative impacts only when using the significance-criterion definition, which is the most stringent definition that requires larger differences between the treatment and control groups in terms of shelter and income potential indicators of gentrification than the other two definitions. These results suggest that the vulnerability of people of color to TIG are highly sensitive to the definitions and measures of TIG. Policy makers and planners need to be aware of the sensitivity and involving stakeholders such as people and color and developers into the deliberation of defining and measuring TIG. Moreover, additional research is needed to explain how and why the variable measuring racial composition of neighborhoods at the time of station opening does not have the impacts, but the variable measuring racial composition of MSA has the impact but varies when using different definitions of TIG.

Chapter 5: Summary and Conclusions

The past three decades (1990 – 2020) have witnessed the emergence and rapid growth of high-quality public transit in the U.S., with large federal, state, and local investment. In the most recent decade, from 2010 to 2019, the total investment in high-quality public transit was $47.5 billion, and the total length of transit routes expanded 1203 miles. These high-quality transit systems usually have been associated with the changes of neighborhoods adjacent to those transit lines, leading to concerns about gentrification, social equity, and potential displacement of low-income and/or minority residents. However, until now, a limited number of studies has focused on the relationship between gentrification the development of high-quality public transit, also called as rapid transit. Only 19 empirical studies have examined the hypothesis of Transit-Induced Gentrification (TIG), which states that the opening of new rapid transit stations could induce gentrification in the neighborhoods that are newly served by those rapid transit stations. These empirical studies have reached different conclusions on the of TIG hypothesis, finding TIG in some cases and not others, and identifying different correlates of TIG. This variation in findings also exists among the examinations of TIG in the same city (Padeiro et al., 2019). Scholars suspect the variation could partly result from the differences in definitions and measures of gentrification, and/or research design across those empirical studies (e.g. Padeiro et al., 2019). In addition, studies of TIG have been completed based on different hypothesis derived from different theoretical frameworks. These hypotheses have tried to incorporate the public transit into the traditional theoretical frameworks of gentrification such as the neoclassical economic framework and the Marxism framework, or have developed new hypotheses to explain TIG. Few studies, however, have empirically examined the factors that associated with the probability of TIG. This lack of empirical evidence makes it difficult to assess the validity of competing hypotheses of TIG. This lack of evidence also makes it difficult to target policies to prevent or alleviate the problems associated with gentrification. Therefore, more comprehensive studies of the TIG hypothesis are needed.

This dissertation is designed to strengthen the evidence needed to elaborate and affirm hypotheses of TIG and to target policy interventions. The dissertation asks two main research questions: *1) Do rapid transit lines induce gentrification in U.S. MSAs?*, and *2) What factors affect the occurrence of transit-induced gentrification in U.S. MSAs?* Chapter 2 reviewed the major literature associated with the TIG. These two questions have been studied Chapter 3 and Chapter 4, respectively.

Chapter 3 used a quasi-experimental design to examine the hypothesis of TIG in all neighborhoods in the U.S. newly served by the rapid transit stations that opened from 2000 through 2009. The treatment group, by definition, is the neighborhoods (approximated by CBGs) newly served by the rapid transit stations that opened from 2000 through 2009; the control group is selected based on the nonparametric propensity score matching, controlling for the neighborhood characteristics prior to the open of rapid transit stations and the impact of Great Recession. Pretest-posttest on a set of indicators of gentrification is conducted and compared between the treatment and control groups that are gentrifiable for the examination of TIG hypothesis. The set includes nine indicators of gentrification covering housing, demographic, and neighborhood income characteristics. Five of these indicators are viewed as the core indicators of gentrification: median property value, median rent, proportion of residents with college education, proportion of residents in professional occupations, and median household income. The other four indicators of gentrification include proportion of owner-occupied dwellings, total occupied housing, total population, and proportion of white residents. In addition to all the rapid-transit-served (RTS) neighborhoods that are gentrifiable as a whole, the examinations of TIG hypothesis have also been conducted for the subgroups of gentrifiable neighborhoods served by different rapid transit modes (i.e., rail, BRT, and high-end BRT). To draw a full picture of the impact of new rapid transit stations, the examinations of more general Transit-Induced Upgrading (TIU) are also conducted in all treated and non-gentrifiable treated neighborhoods, as well as their subgroups of neighborhoods served by different rapid transit modes. Additionally, the examinations are also conducted respectively using two different areal units of analysis—Census block groups and Census tracts to find the better areal unit of analysis for TIG issues, and for both short-term (2000 – 2010) and long-term (2000 – 2016) analyses to verify the stability of examination results. Therefore, in total, there are 24 sets of tests, and each set includes the comparisons between the treatment and control groups on the nine indicators of gentrification.

The results include five major findings. 1) There is evidence of Transit-Induced Gentrification (TIG), but variation and heterogeneity exist across different rapid transit modes. 2) Rail-served neighborhoods have more evidence of gentrification than BRT-served neighborhoods, which have little evidence of gentrification, although among the BRT-served neighborhoods, the ones served by high-end BRT have some evidence of gentrification in demographic indicators. 3) For non-gentrifiable neighborhoods, little evidence of Transit-Induced Upgrading (TIU) has been found, regardless of the rapid transit modes. 4) The long-term analysis generally gives consistent results when comparing with the short-term analysis, but shows stronger evidence of gentrification for gentrifiable neighborhoods served by rail transit. 5) The results using Census block groups (CBGs) as the areal unit of analysis to approximate transit served neighborhoods are generally similar to the results using Census tracts (CTs), but differences exist such as more evidence of gentrification in gentrifiable neighborhoods served by rail and by high-end BRT when using CBGs. These differences are more substantial over short-term than over long-term. These results suggest the use of CBGs could give more valid results than the use of CTs, which are often much larger than the actual areas that could be served by the new rapid transit stations.

Chapter 4 is designed to answer the second research question—*What factors affect the occurrence of transit-induced gentrification in U.S. MSAs?* The research design builds on the design and results of the analyses in Chapter 3. Three definitions are used to develop binary measures of the occurrence of TIG, based on the nine indicators of gentrification defined in Chapter 3. The reason for use of multiple measures is to reduce the risk of statistical bias that could result from the arbitrariness in defining the occurrence of TIG. Based on these three definitions, the differences in the probability of TIG are examined across the three rapid transit modes—rail, BRT, and high-end BRT. On the bases these findings, the two-level hierarchical logistic regression models are used to examine the impact of the MSA and neighborhood (i.e., CBG) characteristics on the probability of TIG, for each of the three definitions of the occurrence of TIG.

The analyses in Chapter 4 have four major findings. 1) The three different definitions of TIG occurrence, with different levels of stringency, indicate, respectively, about 60-70%, 40-50%, and 30-40% of gentrifiable rapid-transit-served CBGs experienced TIG. That different percentages suggest that different definitions of TIG, as expected, result in different estimates of the prevalence of TIG. 2) Gentrifiable treated CBGs have higher percentages of CBGs that experienced TIG when comparing with the percentages of all treated CBGs that experienced TIU, and the long-term analysis shows higher percentages than the short-term analysis, regardless of the definitions. Only the three-criterion definition, however, shows substantial higher percentages of gentrifiable CBGs that experienced TIG in rail-served areas than BRT-served areas. 3) The characteristics of the MSAs show inconsistent evidence of their impact on the probability of TIG across the three different definitions of TIG occurrence. In contrast, the neighborhood (i.e., CBG) characteristics, especially the socioeconomic characteristics, show consistent evidence of impact. To be more specific, evidence of the impact is consistent across the three definitions for some socioeconomic factors of CBGs, especially the factors indicating the disadvantaged status of the neighborhoods such as the proportion of residents below poverty level (with positive impact). The proportion of families with no children has consistent evidence of positive impact, suggesting that neighborhoods with higher proportions of families with no children need more attention for their vulnerability to TIG. In addition, the proportion of employees in manufacturing industry and the proportion of female residents shows negative impact on the probability of TIG. Both the new rapid transit station density around CBG (i.e., the count of new rapid transit stations opened from 2000 through 2009 that are accessible by half-mile walk from the CBG) and one of the two location indicators (i.e., distance to freeway) show negative impacts on the probability of TIG, but the impacts are not consistent across different definitions of TIG. The other location indicator of neighborhood that suggests its distance to CBD and the years since the station opening, however, do not show significant impacts. Other physical characteristics such as the housing unit density at the CBG-level do not show consistent impact across the models. The gentrifiable neighborhoods served by rail transit only show significant higher probability of TIG than those served by BRT under only one of the three definitions—the three-criterion definition. 4) The measure of capital accumulation in the MSA, suggested by the Marxism framework of explaining the TIG, shows little evidence of raising the probability of TIG.

In addition, the three different definitions of the occurrence of TIG in Chapter 4 give different percentages of gentrifiable neighborhoods that experienced TIG, and the models of TIG that use these definitions identify different factors that are significantly associated with the probability of TIG. Based on the analyses in Chapter 4, only the three-criterion definition gives consistent findings with Chapter 3, suggesting that rail transit is more likely to induce gentrification than BRT and among BRT, the high-end BRT are more likely to induce gentrification. Thus, using the three-criterion definition gives more stable and valid conclusions according to the internal comparisons of this dissertation (i.e., the comparisons of findings between Chapter 3 and Chapter 4). However, relative to other, less stringent definitions, the three-criterion definition may underestimate the probability of TIG. The unsurprising fact that use of different definitions and different models leads to different estimates of the pervasiveness of TIG and identifies different correlates of TIG complicates the work of policy-makers and planners responsible for addressing the problem of gentrification. While the model using the three-criterion definition may be "best" from a perspective of internal theoretical validity, in some situations it potentially could fail to predict TIG that adversely affects low-income residents and people of color in neighborhoods with new transit stations.

Through these findings, this dissertation makes four major contributions to the literature. 1) Instead of focusing on the TIG in one or several cities, this dissertation presents a comprehensive examination of the TIG hypothesis in all the MSAs in the U.S. with new rapid transit stations that opened from 2000 through 2009. The study uses the same quasi-experimental research design and the same definition and indicators of gentrification to reduce the risk of statistical bias due to variable research designs and selection of different indicators in the previous studies. The analyses, however, still show the probability of TIG varies and is heterogeneous across different rapid transit modes, across different metropolitan areas, and across neighborhoods with different socioeconomic characteristics. 2) This dissertation, using hierarchical logistic regression analysis, identifies and examines factors that are likely to be associated with the probability of TIG, including physical, infrastructural (of transit), and socioeconomic factors at the MSA-level, as well as the physical and socioeconomic factors at the CBG-level. Through the results, some socioeconomic factors at the CBG-level show consistent impact on the probability of TIG, such as the proportions of residents below poverty level and of families with no children. 3) To better define the areas served by rapid transit stations, Census block groups are used as the areal unit of analysis, and different results have been identified in the examinations of TIG hypothesis when comparing with analyses using Census tracts (which have been used in most previous gentrification studies) under the same research design. To complete these analyses, a longitudinal (2000 – 2016) nation-wide socioeconomic dataset has been created at Census block group and Census tract levels, through interpolation methods of block-level data using *GIS*, *Stata* and *R* jointly. The network analysis is also used in *GIS* to generate and select service areas of transit stations, which is defined as those areas accessible within a half-mile walking distance. 4) The Bus Rapid Transit (BRT) systems have also been included in the examination of TIG hypothesis, and have been compared with the rail systems. More evidence of gentrification has been documented in areas served by rail transit than by BRT, including high-end BRT.

Apart from the contributions to the literature, this dissertation also has some policy implications for urban/transit planners and policy-makers. First, the BRT, because it has a lower probability of TIG and requires less investment than the rail transit, could help extend the transit service to the most vulnerable and thus could be a reasonable substitute for rail transit in some cases. In addition, the identification of neighborhoods with higher probability of TIG could enable policy-makers and planners to target policies to assist the most vulnerable areas and residents. For example, when investments and improvements in transit are planned, the suitable policies such as affordable housing and rent ceiling could be targeted to the neighborhoods with higher poverty rates, with higher proportions of families with no children, and with lower proportions of female residents. In the meantime, the neighborhoods with higher proportions of employees in manufacturing industry, may not need the concerns over TIG.

This dissertation shows that models using different definitions of the occurrence of TIG give different probabilities of TIG and identify different neighborhoods that are vulnerable towards TIG. These findings, in turn, suggest there may be different levels of need or priority for anti-gentrification/displacement policies and that these policies may need to be targeted towards different neighborhoods. In terms of planning practice, these findings underscore the importance of establishing definitions of TIG in a public and transparent way in which the people who are affected most by the TIG can be involved. Public deliberations about the potential for gentrification are needed to minimize the impact of gentrification to the most vulnerable and to increase equity.

Some limitations in this dissertation could be addressed in future studies. First, in the examinations of TIG hypothesis in Chapter 3, the potential endogeneity (i.e., the design of rapid transit lines may choose to pass through the neighborhoods with higher potential for gentrification or already in the process of gentrification) has not been fully solved by selecting the control group through the propensity score matching to control for the initial characteristics of the neighborhood. Future studies are needed to search for more ways to control for the risk of endogeneity. Second, in Chapter 4, some other factors, apart from the factors included in the regression models, have not been examined for their impact on the probability of TIG. These factors include related policies such as the Transit-Oriented Development, the related housing policies, and the anti-gentrification/displacement policies; and include the invisible social characteristics of neighborhoods such as the social capital and the level of local autonomy. In the near future, I plan to collect the related data and explore the impact of those factors.

In addition, displacement, which is presumed to be closely associated with gentrification as one of the major adverse outcomes, has not been addressed in this dissertation. The examinations of TIG hypothesis in this dissertation have suggested faster growth of residents with higher-income or higher-income potential in the rapid-transit-served neighborhoods, especially the gentrifiable rail-served neighborhoods, than their corresponding control groups, but little evidence of faster population and housing growth has been found simultaneously. This result suggests the displacement of lower-income residents prior to the open of station could happen during the gentrification process.

However, these demographic measures are inadequate to draw conclusions on the relationship between TIG and displacement (Marcus, 1985). Displacement is defined as a phenomenon that occurs "when any households is forced to move from its residence by conditions which affect the dwelling or immediate surroundings" (Grier & Grier 1978; Zuk et al., 2018). Displacement has a complex relationship with gentrification. To be more specific, there are different types of displacement and these different types of displacement could be associated with different stages of gentrification or could also be not associated with gentrification (Grier & Grier, 1978; Marcus, 1985; Zuk et al., 2018). In addition, it is also complicated to adequately measure the magnitude of displacement. Scholars have applied a variation of qualitative, quantitative and mixed-methods to measure displacement (e.g., Newman & Owen, 1982; Marcus, 1985 & 1986) and specifically the gentrification-induced displacement (e.g., Freeman & Braconi, 2004; Newman & Wyly, 2006; Wyly et al., 2010). All these measures of displacement require individual data that longitudinally track residents' housing and demographic characteristics, as well as their mobility. These required data are not available currently for nation-wide analysis. Therefore, this dissertation have not explicitly defined and measured displacement, and have not examined the relationship between displacement and TIG. Future efforts are needed to inform those displacement-related questions.

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Appendix: Additional Results for Factors Affecting the Probability of Transit-Induced Upgrading

Table 18 Description of Dependent and Independent Variables
(Including All Census Block Groups Newly Served by Rapid Transit Stations)

Variables	Obs	Mean	Std. Dev.	Min	Max
Dependent Variables (TIG Occurrence)					
Definition 1	1,513	0.6028	0.4895	0	1
Definition 2	1,513	0.4065	0.4913	0	1
Definition 3	1,513	0.3556	0.4788	0	1
Independent Variables					
Metropolitan Area Characteristics					
Physical					
Size					
Total population (2000)	40	2,996,473	3,517,759	129,292	18,323,062
Land areas (square miles)	40	4,917.76	3,137.30	224.56	14,565.75
Transit infrastructure					
Count of rapid transit stations (until 2010)	40	110.25	182.1561	1	935
Existence of prior rapid transit (= 1)	40	0.6750	0.4743	0	1
Socioeconomic					
% of professional (2000)	40	0.3652	0.0455	0.2440	0.4907
% of manufacturing (2000)	40	0.1198	0.0459	0.0368	0.2711
% of college-educated (2000)	40	0.2874	0.0530	0.1733	0.4249
% of unemployed (2000)	40	0.0537	0.0101	0.0350	0.0751
% of white (2000)	40	0.7484	0.1135	0.5242	0.9649
Total housing unit changes (00–10)	40	0.1603	0.1044	-0.0189	0.5012
Debt-to-income ratio (2010)	39	1.9577	0.5281	0.51	2.57
Census Block Group Characteristics					
Physical					
Distance to CBD (miles)	1,513	6.7346	6.4555	0.0516	50.2164
Distance to nearest freeway entrance (miles)	1,513	1.2057	1.4618	0.0149	22.1780
Housing density (2000)	1,513	5019	7344	0.5742	84,284
New transit modes (Rail = 1)	1,513	0.7984	0.4013	0	1
Years since station opened	1,513	5.0397	2.8598	1	10
Count of rapid transit stations (00–10)	1,513	1.0720	0.3012	1	5
Socioeconomic (in 2000)					
% of poverty (2000)	1,513	0.1902	0.1459	0	0.8499
% of professional (2000)	1,513	0.3237	0.1703	0	0.9328
% of manufacturing (2000)	1,513	0.1169	0.0821	0	0.5352
% of college-educated (2000)	1,513	0.2559	0.1940	0	0.9467
% of white (2000)	1,513	0.5830	0.2778	0	0.9999
% of female (2000)	1,513	0.4989	0.0595	0	0.6974
% of families with no children	1,511	0.5192	0.1326	0	1

Table 19 Regression Results of Factors Affect the Occurrence of Transit-Induced Gentrification (Including All Census Block Groups Newly Served by Rapid Transit Stations)

Variables **Report Marginal effects (P-values)**	**Definition 1: Two-criterion definition**					
	MSA-level		**CBG-level**		**MSA & CBG**	
Regression methods	Logit Model 1	HLR Model 2	Logit Model 3	HLR Model 4	Logit Model 5	HLR Model 6
MSA						
Physical						
Size						
Total population (billion)	-2.5997 (0.6968)	-2.5998 (0.5907)			-1.9674 (0.7968)	-1.9674 (0.6501)
Land areas (billion miles)	-0.0091 (0.2048)	**-0.0091*** (0.0634)			-0.0054 (0.5264)	-0.0054 (0.2944)
Transit Infrastructures						
Total rapid transit stations (thousand)	0.0349 (0.7899)	0.0349 (0.7031)			0.0770 (0.5810)	0.0770 (0.4269)
Existence of prior rapid transit	-0.0395 (0.3423)	-0.0395 (0.2420)			-0.0541 (0.3174)	-0.0541 (0.1267)
Socioeconomic						
% of professional	-0.8960 (0.5300)	-0.8960 (0.4421)			-0.2597 (0.8513)	-0.2597 (0.7827)
% of manufacturing	**-1.0094***** (0.0055)	**-1.0094***** (0.0005)			-0.3740 (0.4227)	-0.3740 (0.2552)
% of college educated	-0.5671 (0.6373)	-0.5671 (0.5900)			-0.4657 (0.7154)	-0.4657 (0.5829)
% of unemployed	**-6.1589**** (0.0302)	**-6.1583***** (0.0079)			**-5.2633*** (0.0593)	**-5.2633**** (0.0399)
% of white	-0.3556 (0.1755)	**-0.3556**** (0.0304)			-0.3542 (0.1414)	**-0.3542*** (0.0723)
Capital Accumulation						
Total housing unit changes (00–10)	-0.2500 (0.3349)	**-0.2500*** (0.0976)			-0.3525 (0.2645)	**-0.3525**** (0.0376)
Debt-to-income ratio	**0.0686**** (0.0418)	**0.0686***** (0.0048)			**0.0813**** (0.0398)	**0.0813***** (0.0053)

Table 19 Regression Results of Factors Affect the Occurrence of Transit-Induced Gentrification (Continued)

Variables **Report Marginal effects (P-values)**	**Definition 1: Two-criterion definition**					
	MSA-level		**CBG-level**		**MSA & CBG**	
Regression methods	Logit Model 1	HLR Model 2	Logit Model 3	HLR Model 4	Logit Model 5	HLR Model 6
Census Block Group						
Physical						
Distance to CBD (thousand miles)			0.5663 (0.8109)	0.5663 (0.7588)	0.2608 (0.8973)	0.2608 (0.8945)
Distance to freeway (thousand miles)			-7.4124 (0.5100)	-7.4124 (0.3177)	1.4869 (0.9088)	1.4869 (0.8856)
Housing density (thousand / mile^2) (2000)			**-0.0035*** (0.0682)	**-0.0035***** (0.0002)	-0.0029 (0.1728)	**-0.0029**** (0.0443)
New transit modes (Rail = 1)			0.0379 (0.3104)	0.0379 (0.2709)	0.0523 (0.2022)	0.0523 (0.1938)
Years since station opened			-0.0046 (0.4027)	-0.0046 (0.3865)	-0.0024 (0.6110)	-0.0024 (0.6210)
New station density (2000-2009)			-0.0636 (0.1277)	-0.0636 (0.2212)	-0.0590 (0.2072)	-0.0590 (0.2482)
Socioeconomic (in 2000)						
% of poverty			**0.4211***** (0.0000)	**0.4211***** (0.0000)	**0.4204***** (0.0000)	**0.4204***** (0.0000)
% of professional			0.1176 (0.4935)	0.1176 (0.5019)	0.0793 (0.5771)	0.0793 (0.6476)
% of manufacturing			**-0.6027***** (0.0005)	**-0.6027***** (0.0001)	**-0.6465**** (0.0104)	**-0.6465***** (0.0029)
% of college educated			**-0.2876*** (0.0557)	**-0.2876*** (0.0661)	**-0.2636**** (0.0304)	**-0.2636*** (0.0906)
% of white			0.0192 (0.7357)	0.0192 (0.7659)	0.0329 (0.6058)	0.0329 (0.6825)
% of female			**-0.6193**** (0.0146)	**-0.6193**** (0.0241)	**-0.6519**** (0.0405)	**-0.6519**** (0.0145)
% of families with no children			0.1735 (0.1473)	0.1735 (0.1753)	0.1934 (0.1299)	0.1934 (0.1480)

Table 19 Regression Results of Factors Affect the Occurrence of Transit-Induced Gentrification (Continued)

Variables **Report Marginal effects (P-values)**	**Definition 2: Three-criterion definition**					
	MSA-level		**CBG-level**		**MSA & CBG**	
Regression methods	Logit Model 7	HLR Model 8	Logit Model 9	HLR Model 10	Logit Model 11	HLR Model 12
MSA						
Physical						
Size						
Total population (billion)	-0.4399 (0.9342)	-1.6616 (0.8241)			-0.1291 (0.9850)	-0.1287 (0.9815)
Land areas (billion miles)	-0.0094 (0.1837)	-0.0080 (0.3514)			-0.0029 (0.7180)	-0.0029 (0.5669)
Transit Infrastructures						
Total rapid transit stations (thousand)	0.0546 (0.6315)	0.0896 (0.5126)			0.1042 (0.4149)	0.1042 (0.3108)
Existence of prior rapid transit	**-0.0815**** (0.0383)	-0.0954 (0.1096)			**-0.1129**** (0.0086)	**-0.1129***** (0.0007)
Socioeconomic						
% of professional	-0.2531 (0.8469)	-0.2625 (0.8394)			0.3830 (0.7879)	0.3830 (0.7200)
% of manufacturing	-0.4523 (0.1532)	-0.5747 (0.1219)			0.1515 (0.7479)	0.1515 (0.6201)
% of college educated	-0.5898 (0.6342)	-0.5502 (0.6393)			-0.3850 (0.7515)	-0.3850 (0.6803)
% of unemployed	-4.9397 (0.1318)	**-5.1800*** (0.0664)			-2.9963 (0.3559)	-2.9964 (0.1888)
% of white	-0.0898 (0.6823)	-0.1348 (0.4892)			-0.0295 (0.9107)	-0.0295 (0.8955)
Capital Accumulation						
Total housing unit changes (00–10)	-0.2182 (0.3931)	-0.2366 (0.3014)			-0.4182 (0.1196)	**-0.4182**** (0.0210)
Debt-to-income ratio	0.0628 (0.1080)	0.0573 (0.1479)			**0.0944***** (0.0042)	**0.0944***** (0.0023)

Table 19 Regression Results of Factors Affect the Occurrence of Transit-Induced Gentrification (Continued)

Variables **Report Marginal effects (P-values)**	**Definition 2: Three-criterion definition**					
	MSA-level		**CBG-level**		**MSA & CBG**	
Regression methods	Logit Model 7	HLR Model 8	Logit Model 9	HLR Model 10	Logit Model 11	HLR Model 12
Census Block Group						
Physical						
Distance to CBD (thousand miles)			1.2350 (0.5024)	0.9997 (0.6514)	1.3414 (0.5220)	1.3413 (0.5473)
Distance to freeway (thousand miles)			-6.5031 (0.5626)	-6.8483 (0.2549)	-4.2221 (0.7613)	-4.2223 (0.6289)
Housing density (thousand / mile^2) (2000)			**-0.0042**** (0.0447)	**-0.0041***** (0.0046)	-0.0045 (0.1312)	**-0.0045*** (0.0773)
New transit modes (Rail = 1)			0.0502 (0.1413)	**0.0517*** (0.0907)	**0.0753**** (0.0481)	**0.0753**** (0.0277)
Years since station opened			-0.0003 (0.9514)	0.0004 (0.9461)	0.0013 (0.7922)	0.0013 (0.8115)
New station density (2000-2009)			-0.0101 (0.8410)	-0.0096 (0.8457)	-0.0014 (0.9728)	-0.0014 (0.9779)
Socioeconomic (in 2000)						
% of poverty			**0.4083***** (0.0003)	**0.3943***** (0.0000)	**0.4194***** (0.0009)	**0.4194***** (0.0000)
% of professional			0.2487 (0.1087)	0.2318 (0.1158)	0.2125 (0.2486)	0.2125 (0.1732)
% of manufacturing			**-0.3841**** (0.0308)	**-0.4058***** (0.0070)	**-0.5346**** (0.0112)	**-0.5346***** (0.0037)
% of college educated			**-0.3371**** (0.0252)	**-0.3265**** (0.0138)	**-0.3023**** (0.0186)	**-0.3023**** (0.0226)
% of white			0.0228 (0.7239)	0.0290 (0.7323)	0.0133 (0.8291)	0.0133 (0.8948)
% of female			**-0.5019*** (0.0919)	**-0.4881*** (0.0880)	**-0.5477**** (0.0202)	**-0.5477*** (0.0594)
% of families with no children			**0.3678***** (0.0001)	**0.3696***** (0.0030)	**0.3695***** (0.0051)	**0.3695***** (0.0038)

Table 19 Regression Results of Factors Affect the Occurrence of Transit-Induced Gentrification (Continued)

Variables **Report Marginal effects (P-values)**	**Definition 3: Significance-criterion definition** **MSA-level**		**CBG-level**		**MSA & CBG**	
Regression methods	Logit Model 13	HLR Model 14	Logit Model 15	HLR Model 16	Logit Model 17	HLR Model 18
MSA						
Physical						
Size						
Total population (billion)	0.1533 (0.9822)	0.1533 (0.9771)			0.4188 (0.9445)	0.4190 (0.9087)
Land areas (billion miles)	**-0.0162**** (0.0141)	**-0.0162**** (0.0120)			-0.0100 (0.2185)	**-0.0100**** (0.0296)
Transit Infrastructures						
Total rapid transit stations (thousand)	0.0039 (0.9757)	0.0039 (0.9681)			0.0467 (0.6810)	0.0467 (0.6018)
Existence of prior rapid transit	-0.0183 (0.6560)	-0.0183 (0.6743)			-0.0469 (0.2660)	-0.0469 (0.1637)
Socioeconomic						
% of professional	**-2.1291**** (0.0480)	**-2.1291*** (0.0679)			-1.3015 (0.4155)	-1.3015 (0.2287)
% of manufacturing	-0.5553 (0.1834)	**-0.5553*** (0.0937)			0.0587 (0.8953)	0.0587 (0.8394)
% of college educated	0.5998 (0.5553)	0.5998 (0.5710)			0.7370 (0.5732)	0.7370 (0.4598)
% of unemployed	-3.9651 (0.1460)	-3.9651 (0.1830)			-1.3860 (0.5937)	-1.3860 (0.6402)
% of white	**-0.3899*** (0.0560)	**-0.3899**** (0.0265)			-0.1918 (0.3282)	-0.1918 (0.2672)
Capital Accumulation						
Total housing unit changes (00–10)	0.1247 (0.5936)	0.1247 (0.5248)			-0.0040 (0.9883)	-0.0040 (0.9804)
Debt-to-income ratio	0.0078 (0.8003)	0.0078 (0.8296)			0.0467 (0.1535)	0.0467 (0.1568)

Table 19 Regression Results of Factors Affect the Occurrence of Transit-Induced Gentrification (Continued)

Variables **Report Marginal effects (P-values)**	**Definition 3: Significance-criterion definition**					
	MSA-level		**CBG-level**		**MSA & CBG**	
Regression methods	Logit Model 13	HLR Model 14	Logit Model 15	HLR Model 16	Logit Model 17	HLR Model 18
Census Block Group						
Physical						
Distance to CBD (thousand miles)			0.5103 (0.8473)	0.5103 (0.8524)	0.1427 (0.9592)	0.1429 (0.9601)
Distance to freeway (thousand miles)			0.6104 (0.9470)	0.6104 (0.9528)	17.0166 (0.1598)	17.0166 (0.1108)
Housing density (thousand / mile^2) (2000)			-0.0029 (0.2109)	**-0.0029***** (0.0099)	-0.0026 (0.2889)	-0.0026 (0.1218)
New transit modes (Rail = 1)			0.0541 (0.1210)	**0.0541*** (0.0849)	**0.0686**** (0.0483)	**0.0686*** (0.0522)
Years since station opened			-0.0007 (0.8770)	-0.0007 (0.8804)	0.0009 (0.7960)	0.0009 (0.8435)
New station density (2000-2009)			0.0103 (0.7767)	0.0103 (0.8177)	0.0130 (0.7428)	0.0130 (0.7777)
Socioeconomic (in 2000)						
% of poverty			**0.4689***** (0.0000)	**0.4689***** (0.0001)	**0.4801***** (0.0000)	**0.4801***** (0.0003)
% of professional			-0.0736 (0.6541)	-0.0736 (0.6672)	-0.0706 (0.6933)	-0.0706 (0.6933)
% of manufacturing			**-0.3974**** (0.0285)	**-0.3974***** (0.0011)	**-0.4827***** (0.0073)	**-0.4827***** (0.0006)
% of college educated			-0.0048 (0.9718)	-0.0048 (0.9739)	-0.0055 (0.9681)	-0.0055 (0.9723)
% of white			**-0.1262*** (0.0546)	**-0.1262**** (0.0422)	**-0.1290*** (0.0580)	**-0.1290*** (0.0863)
% of female			**-0.6413**** (0.0140)	**-0.6413***** (0.0005)	**-0.6153***** (0.0036)	**-0.6153***** (0.0006)
% of families with no children			**0.2360*** (0.0752)	**0.2360*** (0.0930)	**0.2424**** (0.0300)	0.2424 (0.1090)