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16. ABSTRACT

Although local and regional planning entities have attempted to direct growth into transit corridors to achieve the sustainability goals of California Senate Bill 375 (SB 375), little is known about the complexity of near-transit infill dynamics. This project aims to enhance our understanding of the relationship between transit investment and urban land use change through a systematic investigation of parcel-level land use in Southern California with a focus on the first phase of the Gold Line, opened in 2003. Our multinomial logistic regression results indicate that vacant parcels within the vicinity of new transit stations are more likely to be developed not only for residential but also for other urban purposes, than those with limited transit accessibility.

Although relatively small in terms of magnitude, the presence of long-term (or indirect) effects is also detected, suggesting that continuing investment in a transit system can benefit both new and existing station areas by promoting the utility of the overall public transit service. Transit stations with low ridership, however, tend to generate smaller land use impacts, indicating the importance of the vitality of transit service. Transit investment's impacts on industrial site reuse also appears to be less evident, while transit investment seems to function as a facilitator of the site redevelopment for multi-family housing and urban open space.

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RESEARCH PROJECT

Infill Dynamics in Rail Transit Corridors: Challenges and Prospects for Integrating Transportation and Land Use Planning

June 2016

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Abstract

Although local and regional planning entities have attempted to direct growth into transit corridors to achieve the sustainability goals of California Senate Bill 375 (SB 375), little is known about the complexity of near-transit infill dynamics. This project aims to enhance our understanding of the relationship between transit investment and urban land use change through a systematic investigation of parcel-level land use in Southern California with a focus on the first phase of the Gold Line, opened in 2003. Our multinomial logistic regression results indicate that vacant parcels within the vicinity of new transit stations are more likely to be developed not only for residential but also for other urban purposes, than those with limited transit accessibility. Although relatively small in terms of magnitude, the presence of long-term (or indirect) effects is also detected, suggesting that continuing investment in a transit system can benefit both new and existing station areas by promoting the utility of the overall public transit service. Transit stations with low ridership, however, tend to generate smaller land use impacts, indicating the importance of the vitality of transit service. Transit investment's impacts on industrial site reuse also appears to be less evident, while transit investment seems to function as a facilitator of the site redevelopment for multi-family housing and urban open space.

I. Introduction

In the domain of planning research and practice, a great deal of attention has been paid to the potential of systematic integration of transportation and land use planning in achieving a more sustainable form of urban development. More specifically, in the State of California, transit-oriented infill development has been employed as a major strategy for reducing vehicle miles traveled (VMT) and associated greenhouse gas (GHG) emissions from passenger vehicles and attaining other sustainability goals of the Senate Bill 375 (SB 375). For instance, the Southern California Association of Governments (SCAG) recently adopted the region's 2016-2040 Regional Transportation Plan (RTP) / Sustainable Communities Strategy (SCS) which called for nearly 50% of new employment and housing growth to occur in its High-Quality Transit Areas (HQTA), defined as "generally a walkable transit village ... within one half-mile of a well-serviced transit stop or a transit corridor with 15-minute or less service frequency during peak commute hours" (SCAG, 2016, p.189). In addition, local governments, such as Los Angeles, California, are developing plans which promote nearby transit-oriented development (TOD) in order to make neighborhoods more compact, mixed-use, and transit accessible to achieve SCS goals (Lane, 2008; Boarnet et al., 2011). The Los Angeles County Metropolitan Transportation Authority's (LACMTA, "Metro") long-range plan also commits funds to new light rail transit (LRT) lines scheduled to open by 2019 (LACMTA, 2009).

These initiatives have been informed by the sizeable literature on the systematic connections between transportation and land use. Studies have investigated the influences of land use characteristics on travel behavior and suggested that an appropriate mix of land use, residential density and street connectivity play a critical role in determining VMT, transit usage, and physical activities (see e.g., Cervero and Kockleman, 1997; Boarnet and Sarmiento, 1998; Ewing and Cervero, 2001 and 2010; Saelens et al., 2003; Salon et al., 2012). More recent studies have also attempted to expand the land use metrics to better represent the detailed configuration of land use beyond traditional density or entropy indicators so as to better understand how land use influences travel patterns (see e.g., Day et al., 2006; Boarnet et al., 2011). A similarly large number of studies have investigated the reverse: how a change or intervention on the side of transportation systems and infrastructure can affect land use and real estate market prices (see e.g., Knight and Trygg, 1977; Huang, 1996; Vessali, 1996; Cervero and Landis, 1997; Giuliano, 2004; Bartholomew and Ewing, 2011). Scholarly attention has also been paid to the importance of land use-transportation integration in realizing a more efficient urban spatial structure and promoting local/regional economic development (Cervero, 2001; Kim, 2011).

We know relatively little, however, about the expected nature and magnitude of the impact that transit system development or expansion will have on nearby infill development dynamics. Although prior research does contribute to our understanding of the potential land use impacts of transit systems, existing studies often regard transit stations as a homogeneous entity (or amenity) and neglect the substantial variation in transit system types, service quality, local plans, and other associated factors that could generate a systematic difference in land use outcomes near transit. Furthermore, little is known about how the dynamic changes in a transit system can shape and re-shape land use patterns within immediate vicinities of stations and broader corridor areas, although it has been suggested that land markets would start to react even before the initial development (Knaap et al., 2001; McMillen and McDonald, 2004).

This research project aims to enhance our understanding of the land use impacts of transit through an investigation of land use change dynamics in relation to transit system development and expansion in Southern California. We use a historical geo-database of the changes in transit systems and land use to identify key factors that shape land use patterns, with a focus on the areas around rail transit stations in Los Angeles County. Attention is paid to land use change dynamics near thirteen stations along the first phase of the Gold Line, which opened in 2003, while consideration is also given to the other station areas in the region. By analyzing parcel-level land use change patterns near the Los Angeles transit system that has expanded substantially over the last two decades, we attempt to provide critical insights into the mechanisms between urban transit expansion and land (re)development processes and meaningful lessons for guiding the local, regional, and state-level initiatives to create more (socially, economically, and environmentally) sustainable communities through a more systematic integration of transportation and land use planning.

II. Brief Literature Review – What does the existing research tell us?

Previous research often focused on the impacts of transit development on land value appreciation (rather than changes in detailed land use) or the general bi-directional interaction between land use and transportation. However, reviewing early studies on real estate development impacts of urban rail systems in North America, Huang (1996) provided some useful insights into how transit can influence urban land use. More specifically, the author suggested that the effects of transit on land use are highly dependent on zoning and many social-economic factors. According to Huang (1996), it was unclear whether transit investment is the most cost-effective way to shape urban form, as planners intended. Vessali (1996) also provided a systematic review of studies concerning the changes brought by transit system development and highlighted several points that were presented in these early studies, including that the effects of transit on land use development might not always be substantial and often required the presence of other complementary factors. Common limitations and constrains found in the early studies were also discussed in Vessali's (1996) review. According to the author, few studies employed statistical models to control for confounding factors (that could affect land use and might be related to transit) and, therefore, measuring the exact extent to which transit development shaped land use remained as a subject of further research. Moreover, most of the early efforts were made to investigate the impacts of heavy rail, as opposed to light rail or bus transit systems that deserved more attention.

More recent studies (published after 1996) tended to utilize more sophisticated statistical models and take advantage of better access to detailed data sets. The coverage of study has also expanded significantly. In particular, a growing number of studies have been devoted to assessing the impacts of light rail and bus rapid transit systems. In terms of findings, however, these recent studies are not completely distinct from those of early research. Rather, they have reinforced the major findings from early research, while recent work has indeed contributed to refining our understanding. For instance, the importance of complementary policies and land use plans has been recognized in recent studies (Cervero and Landis, 1997; Polzin, 1999; Handy, 2005; Loukaitou-Sideris, 2010). In addition, similar to earlier research, most (quantitative) studies have acknowledged difficulties in distinguishing the effects of transit development on land use changes from those of other factors due to the complex nature of the transportation-land use nexus (Pan and Zhang, 2008; Cervero and Kang, 2011; Jun, 2012; Hurst and West, 2014; Ahmad et al., 2016). It has also been suggested that transit systems can lead to land use conversion toward more capital-intensive uses (e.g., for commercial or other business actives) in nearby areas (Duncan, 2008; Pan and Zhang, 2008; Cervero and Kang, 2011; Grube-Cavers and Patterson, 2015).

The intensification of land use in transit corridors is clearly demonstrated in a recent empirical study conducted by Hurst and West (2014). Using the parcel-level data in Minneapolis, Minnesota for 1997-2010, the authors investigated the changes in land use patterns along the Metro Blue Line (light rail), for which construction started in 2001 and service operations began in 2004. They found that vacant land and industrial sites were replaced by residential and commercial buildings (especially multi-family residential uses, which showed the largest increase) and suggested that these land use changes were associated with the proximity to the light rail system. Moreover, they compared the magnitudes of impacts at different time points – i.e., before construction, during construction, and after operation – and detected the largest and smallest impacts before construction and during the construction project, respectively.

Empirical evidence of such land use intensification has also been reported by studies focusing on cases in other countries. For instance, Pan and Zhang (2008) looked into the changes in land use patterns along with the rapid rail lines in Shanghai, China, and found that in near-station areas, high-density and capital-intensive land uses, such as commercial and transportation-related facilities, increased. They also detected a substantial increase in the average Floor Area Ratio (FAR) along the corridors. Similarly, through an investigation of the Bus Rail Transit (BRT) system in Seoul, Korea using multi-level logit models, Cervero and Kang (2011) reported that single-family land uses along the BRT lines were replaced by more intensive uses, such as multi-family housing and mixed development, specifically after the service improvement with creation of dedicated bus-lanes. Furthermore, the authors provided evidence suggesting that transit accessibility can generate land price premiums. Later, another study (Jun, 2012) examined the same area and concluded that the impacts of the BRT system tended to be more significant on non-residential land uses than on residential areas.

Some other studies, mainly through in-depth investigations of their study areas, have stressed the importance of local actions, often implemented in conjunction with or as a reaction to transportation projects. In their largely-cited 1997 study, Cervero and Landis examined the Bay Area Rapid Transit (BART) and its long-term impacts on land use changes with careful consideration of local conditions and neighborhood factors that could play a critical role. Their study suggested that: i) BART's land-use impacts were not evenly distributed and appeared to be associated with local factors; ii) light rail proximity could be an important contributor to land development, but it alone would not be a sufficient condition to lead to significant land use changes; and iii) freeway proximity could be more influential in determining employment and office growth rates than BART. In the study, the authors also paid attention to how local policy instruments were used. For example, they looked at downtown San Francisco and found that the area was emerging as an international financial center with supportive policies aiming at certain types of land development, such as tax increment financing and density bonuses (Cervero and Landis, 1997). As one of the biggest investments in the area, BART played a critical role in improving accessibility, lessening congestion, and thus supporting the economic growth of the downtown. Using the case of the Daly City corridor as a counterexample, the authors also pointed out the possibilities of policy changes with the presence or absence of community support.

Loukaitou-Sideris (2010) provided a systematic comparison of development near two light rail lines in Southern California: the Blue and Gold lines in Los Angeles County, one of which was thought of as a failure, whereas the other was often recognized as a success. This study compared two lines in terms of ridership and the amount/type of development permits issued around station areas to reveal what can make a TOD project successful. It also relied on interviews with architects, urban planners, city officials, and developers, and suggested that the success of TOD projects would depend on stakeholders' perceptions and coordination, as well as existing socio-economic conditions in the project areas.

More recently, Grube-Cavers and Patterson (2015) conducted an investigation of Canadian cities with a focus on possible adverse effects of transit investment on communities. According to the authors, public investment could induce gentrification and thus result in displacement and/or conflicts within the communities, while providing affordable housing opportunities near transportation stations could help minimize such negative consequences (see e.g., Kahn, 2007; Zuk et al., 2015; Dawkins and Moeckel, 2016). Recent studies focusing on energy saving and air quality concerns have shifted the goal of public transit investment away from serving people who were living in densely-occupied areas with high need of public transit service, towards addressing the needs of those who previously traveled by automobile (Polzin, 1999). This shift has called for active and strong involvement of municipalities to publicize the advantage of commuting by transit than by personal vehicle, in many cases by stressing the benefits of TOD and sustainable communities. While rapid technological advances in automobile energy efficiencies and emissions would "have lessened the contribution to air quality improvement that transit can make" (Polzin, 1999, p.136), given the urgent need to curb sprawl and address environmental issues, planners may need to keep putting public transit ahead of other policy tools. However, the importance of social equity should not be underestimated in devising and implementing transit-oriented policy initiatives and other municipal actions.

III. Study Areas & Local Contexts

III-1. Overview

To analyze the land use impacts of transit development and expansion, in this project we focus on public (light rail) transit corridor areas in Los Angeles County, particularly thirteen stations along Phase I of the Gold Line. In this region, the Metro Blue Line started to provide service with 22 stations opened in 1990. The Metro Red and Purple Lines were added in 1993, covering Downtown Los Angeles, Hollywood, Mid-Wilshire, and North Hollywood. In 1995, the transit system was further augmented by the Green Line, offering service to suburban locations in the county (14 stations, approximately 20 miles) without passing Downtown Los Angeles. Later, the Metro Gold (the main focus of this research) and Expo Lines started to operate in conjunction with the existing system. Some of these lines are expected to be extended more in the near future.[1]

The Gold Line Phase I is selected as the focus of this study for multiple reasons. First, the Gold Line Phase I stations are located in three different cities in Los Angeles County, and this variation allows examination of different policy contexts and their potential impacts on transformation of near-transit land use. The City of South Pasadena, for example, uses a Specific Plan to incentivize development in the entire community district surrounding their Mission

[1] Please refer to https://www.metro.net/interactives/metrorail_timeline/ for a more detailed description of the future plans, as well as the 25 years of history. It also needs to be noted that we use the LACMTA rail network data (in line and point shapefile formats). The shapefiles contain the six Metro lines (the Blue, Red, Purple, Green, Gold, and Expo Lines) and 83 stations available in 2012. More detailed information about individual lines and stations is also collected from multiple other sources, including the Metro website and http://metroprimaryresources.info/. Figure 1 presents the metro rail system map obtained from the Metro website, specifically at http://media.metro.net/riding_metro/maps/images/rail_map.pdf.

station, whereas other cities tend to focus incentives only in areas immediately surrounding transit stations. Other differences also exist across municipalities which warrant examination of transit corridor areas that cross jurisdictional boundaries (Loukaitou-Sideris, 2010).

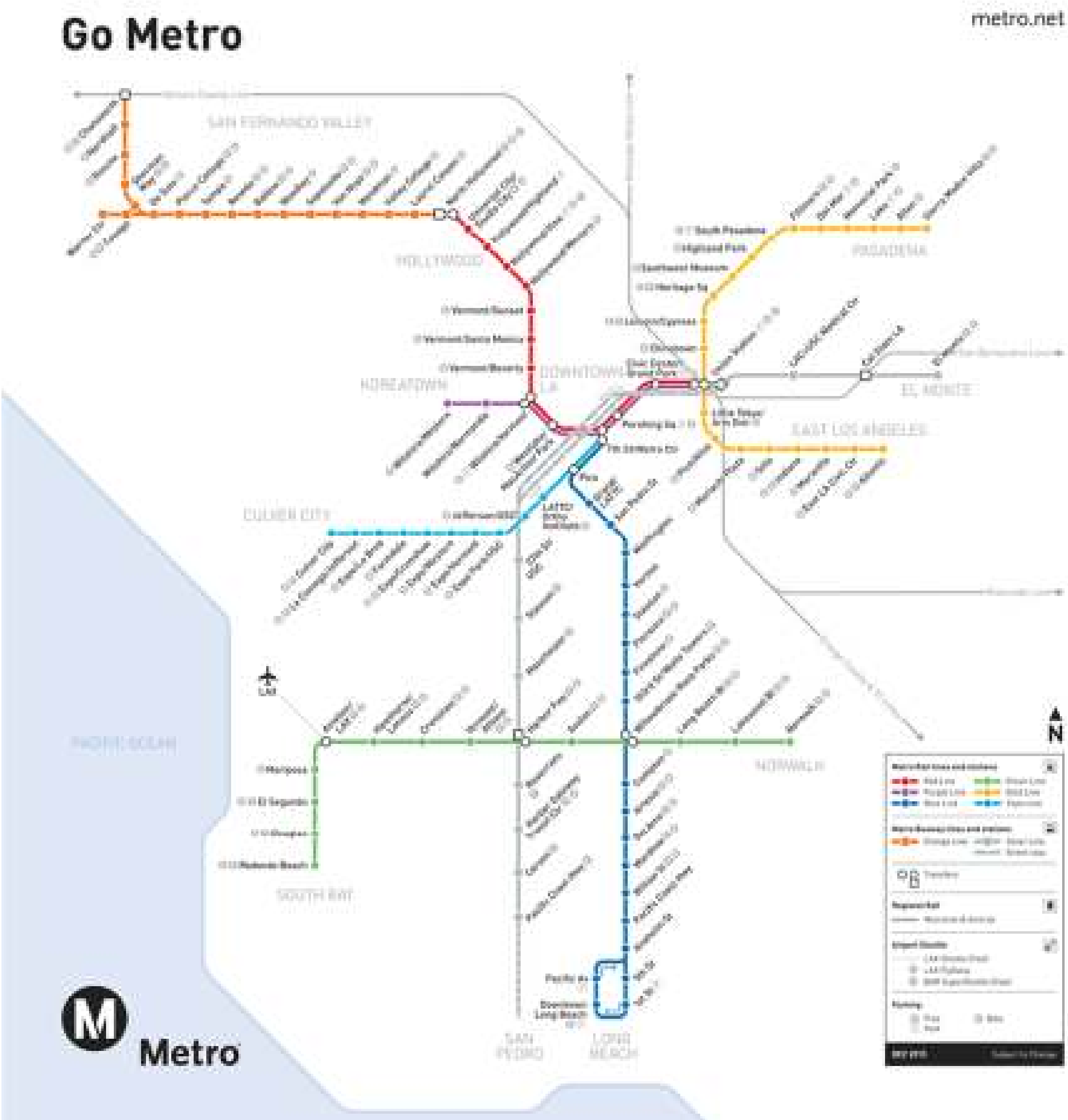

Figure 1. LACMTA/Metro system map
(Retrieved from the Metro website in December 2015)

The Gold Line Phase I stations are also selected because they are located in areas of diverse socioeconomic conditions. Some stations, particularly at the south end of the Gold Line Phase I segment near Downtown Los Angeles, are located in relatively low-income, ethnic minority communities. Others, like those located in South Pasadena and Pasadena, are in wealthier areas with high rates of white-collar employment and education. The varying socioeconomic conditions among different stations allow for examination of different factors and conditions that could potentially impact the relationship between transit and land use (Loukaitou-Sideris et al., 2007).

Data availability is another reason the Gold Line is selected. Parcel-level land use data, provided by SCAG, is available for several years both prior to and after the opening of the Gold Line Phase I (in 2003). For these years, other sources of information are also more accessible. The presence of the Gold Line expansion makes an even more compelling case for focusing on this part of the Los Angeles rail transit system. The Gold Line was extended in 2009 with the Gold Line Eastside Expansion, connecting Downtown Los Angeles to East Los Angeles.

Figure 2 shows the Gold Line Phase I stations located in the three cities and each station's characteristic in terms of land use typology, provided by a Gold Line corridor study (Loukaitou-Sideris et al., 2007). As shown in the map, the first six stations are located in the City of Los Angeles (Union, Chinatown, Lincoln Heights/Cypress Park, Heritage Square/Arroyo, Southwest Museum, and Highland Park); the following Mission Station is located in South Pasadena; and the remaining six stations are in the City of Pasadena (Fillmore, Del Mar, Memorial Park, Lake, Allen, and Sierra Madre Villa).

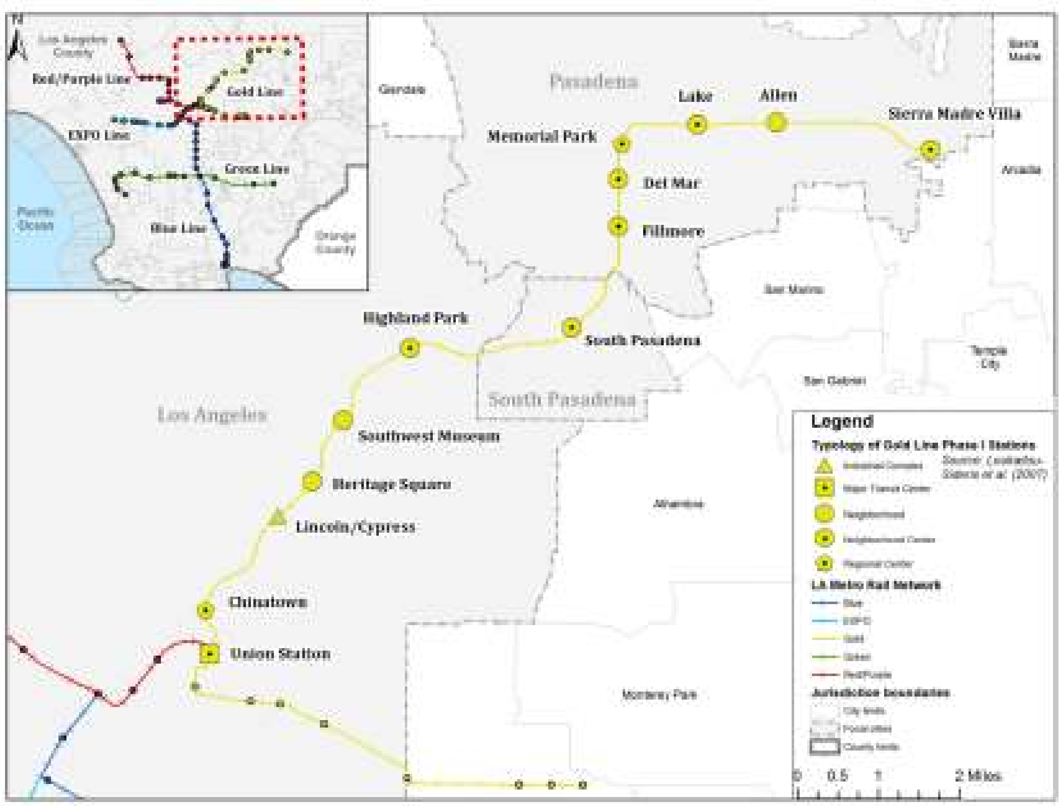

Figure 2. Typology of Gold Line Phase I stations

These stations serve communities with diverse populations and activities. In the heart of Downtown Los Angeles, Union Station is a major transit hub serving a large number of daily passengers. Next, the Chinatown station is a regional destination surrounded by dense housing and commercial land uses. By contrast, most of the stations at the north end of the line in the City of Pasadena are surrounded by more neighborhood-oriented land uses such as residences and local shops (Loukaitou-Sideris et al., 2007).

The following describes more detailed characteristics of the Gold Line Phase I station areas. A set of maps (Figures 3 through 15) are provided to profile the spatial variation in key indicators, based on two sets of Census data: year 2000 (top) and year 2011 (bottom, using the American Community Survey (ACS) 5-year estimates, 2009-2013). In addition to the Census data sets, we utilize other sources of relevant information to explore some additional dimensions of study area characteristics.

III-2. Population Characteristics

The region where the Gold Line is located is one of the most densely populated urban areas in the State of California. As can be seen from the maps in Figure 3, the population per square mile exceeds 5,000 in many parts of the corridor. Some station areas such as Lake in Pasadena, and Highland Park, Union Station, and Chinatown in Los Angeles have much of their populations exceeding 15,000 people per square mile. In Pasadena, at the northern end of the Gold Line Phase I, there is more population around stations and areas become less dense further away from the stations.

Figure 4 shows the average people per household in station areas. There is a noticeable difference in the average number of persons per household between some stations in Pasadena (i.e., Fillmore, Del Mar and Memorial Park), compared with several in Los Angeles (i.e., Lincoln/Cypress, Heritage Square and Highland Park) exhibiting relatively larger numbers of household members. Overall, there appears to have been a decrease in the number of people per household from the year 2000 to 2011.

There is considerable ethnic diversity in many station areas along the Gold Line. Figures 5 through 8 show the percentage of population who are Hispanic, non-Hispanic African American, non-Hispanic Asian, and foreign-born, respectively. Several station areas in Los Angeles, including Lincoln/Cypress, Heritage Square, Southwest Museum, and Highland Park, are home to large numbers of Hispanic populations (Figure 5). Non-Hispanic African Americans live in large percentages near Union Station and along the Gold Line and just north of it in Pasadena (Figure 6). The communities with the highest percentages of non-Hispanic Asian people are located to the southeast of the Gold Line Phase I (Figure 7, specifically a concentration on the right hand side of the maps), while foreign-born people are found to live near Chinatown and Lincoln/Cypress (Figure 8).

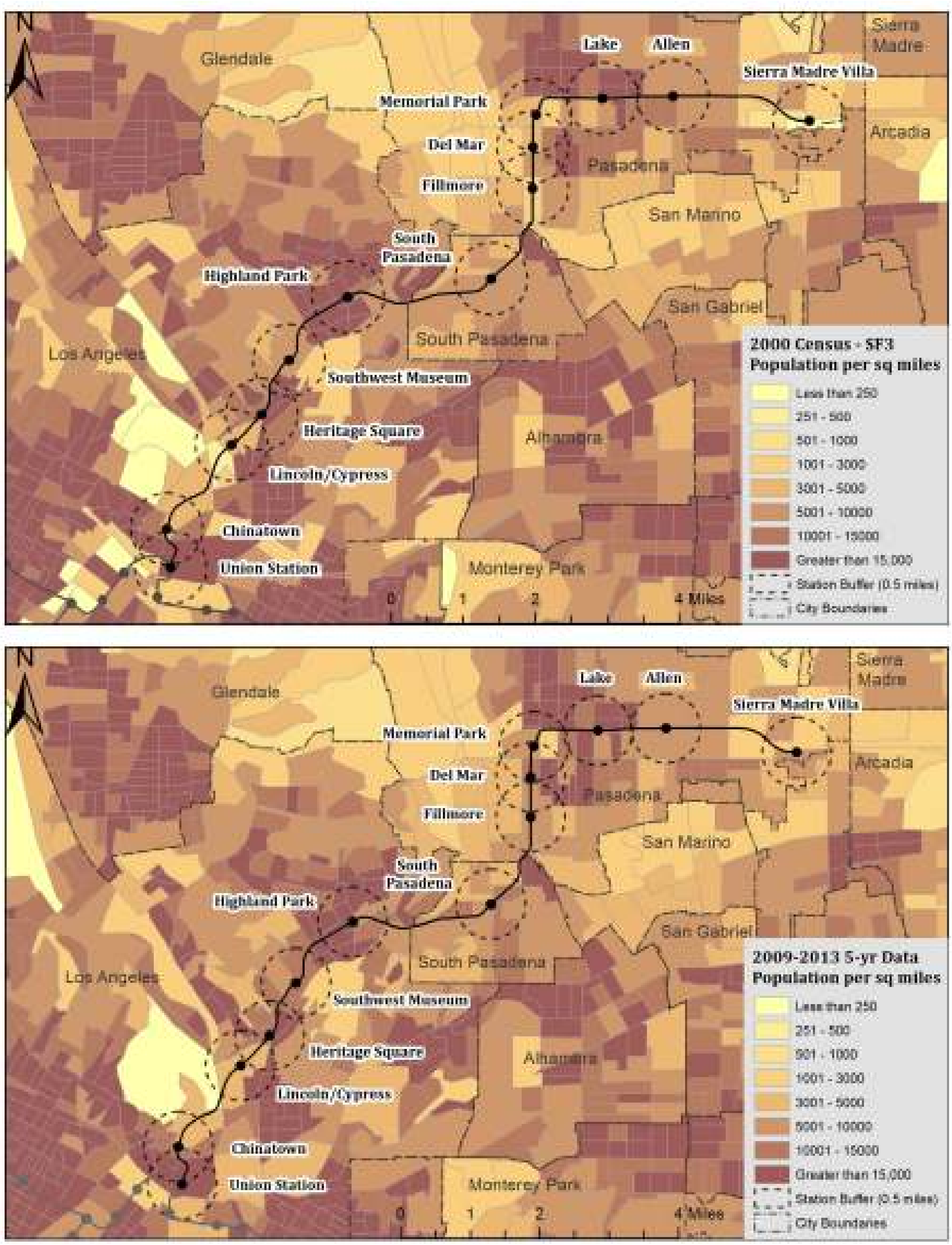

Figure 3. Population per square miles

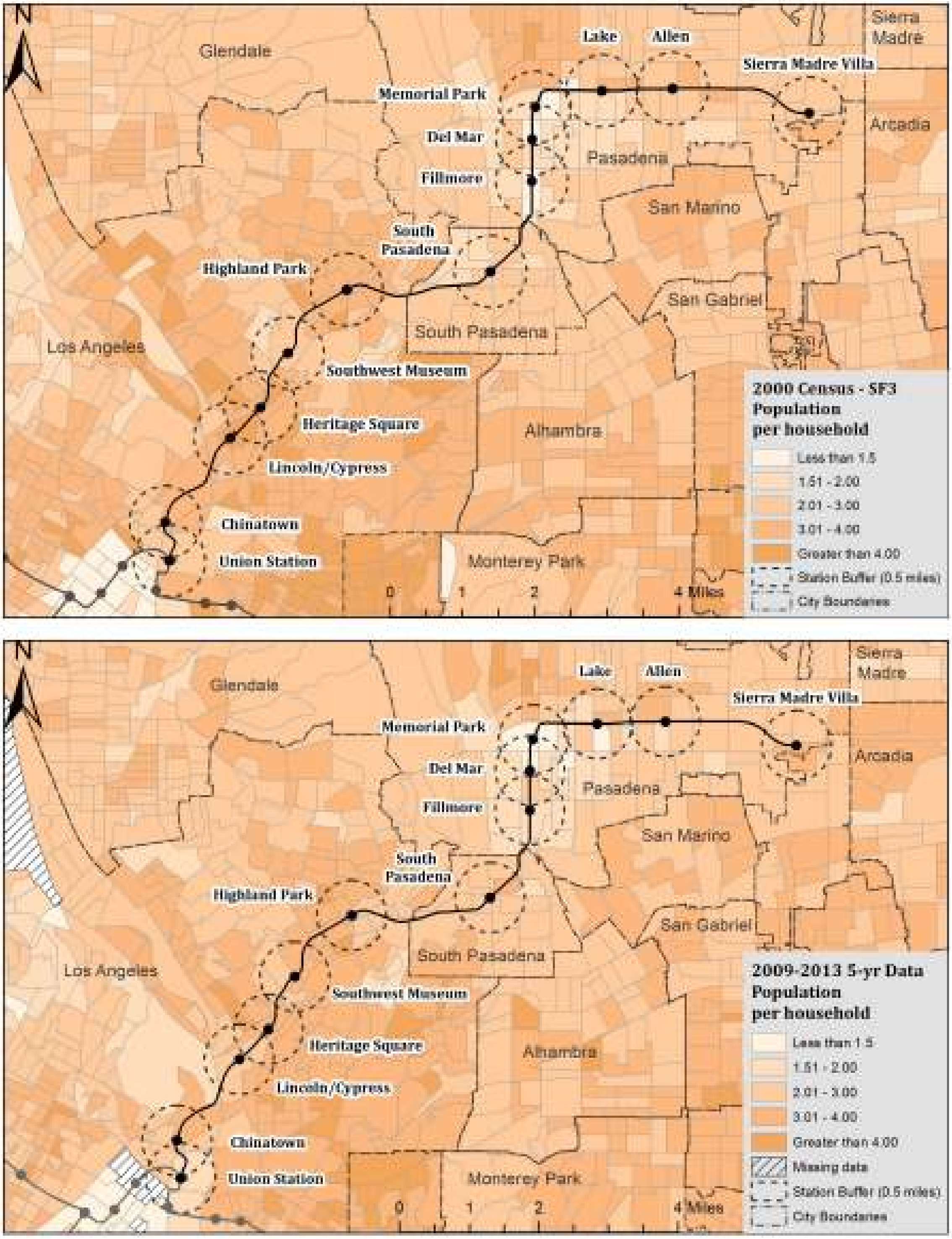

Figure 4. Population per household

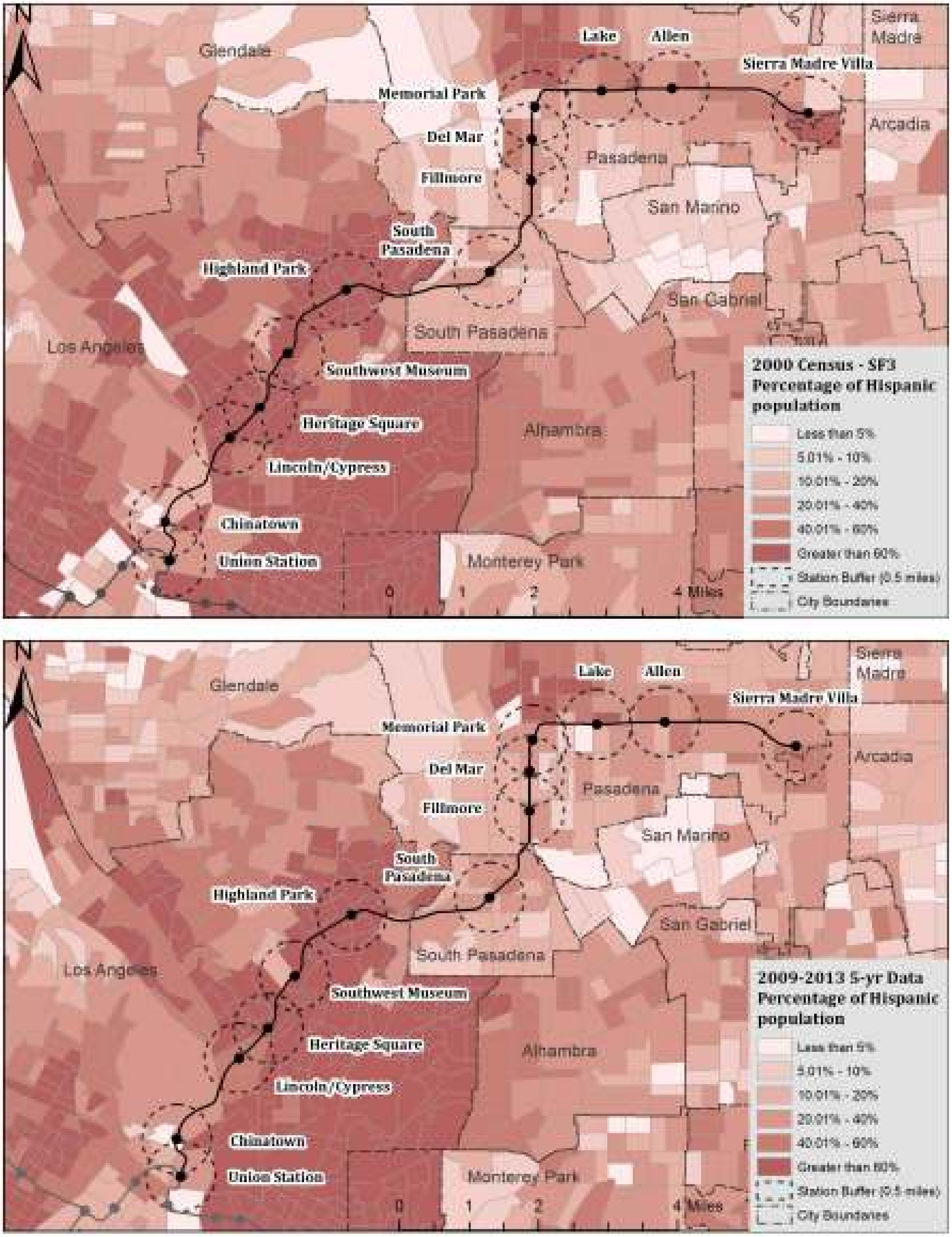

Figure 5. Percentage of Hispanic population

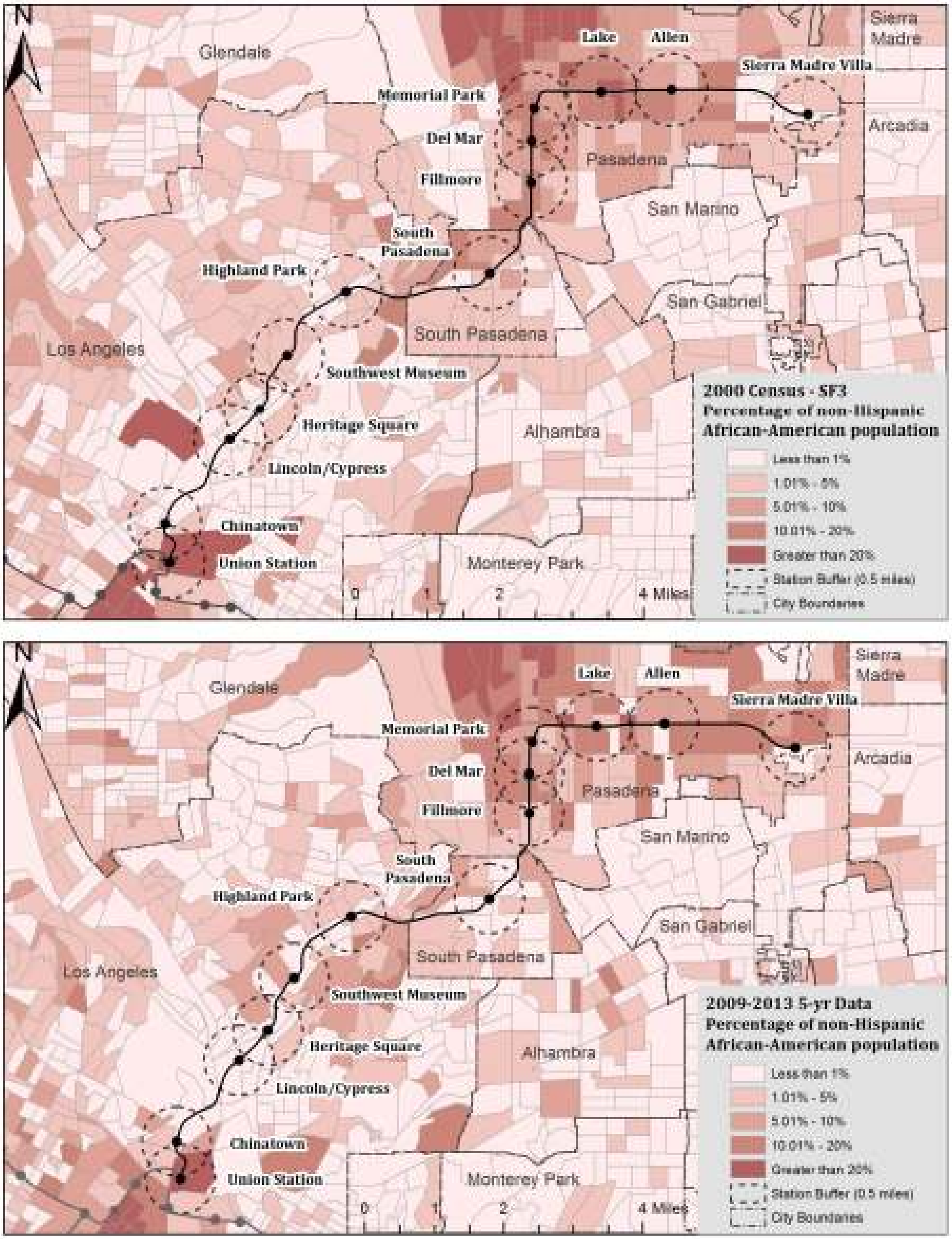

Figure 6. Percentage of non-Hispanic African American population

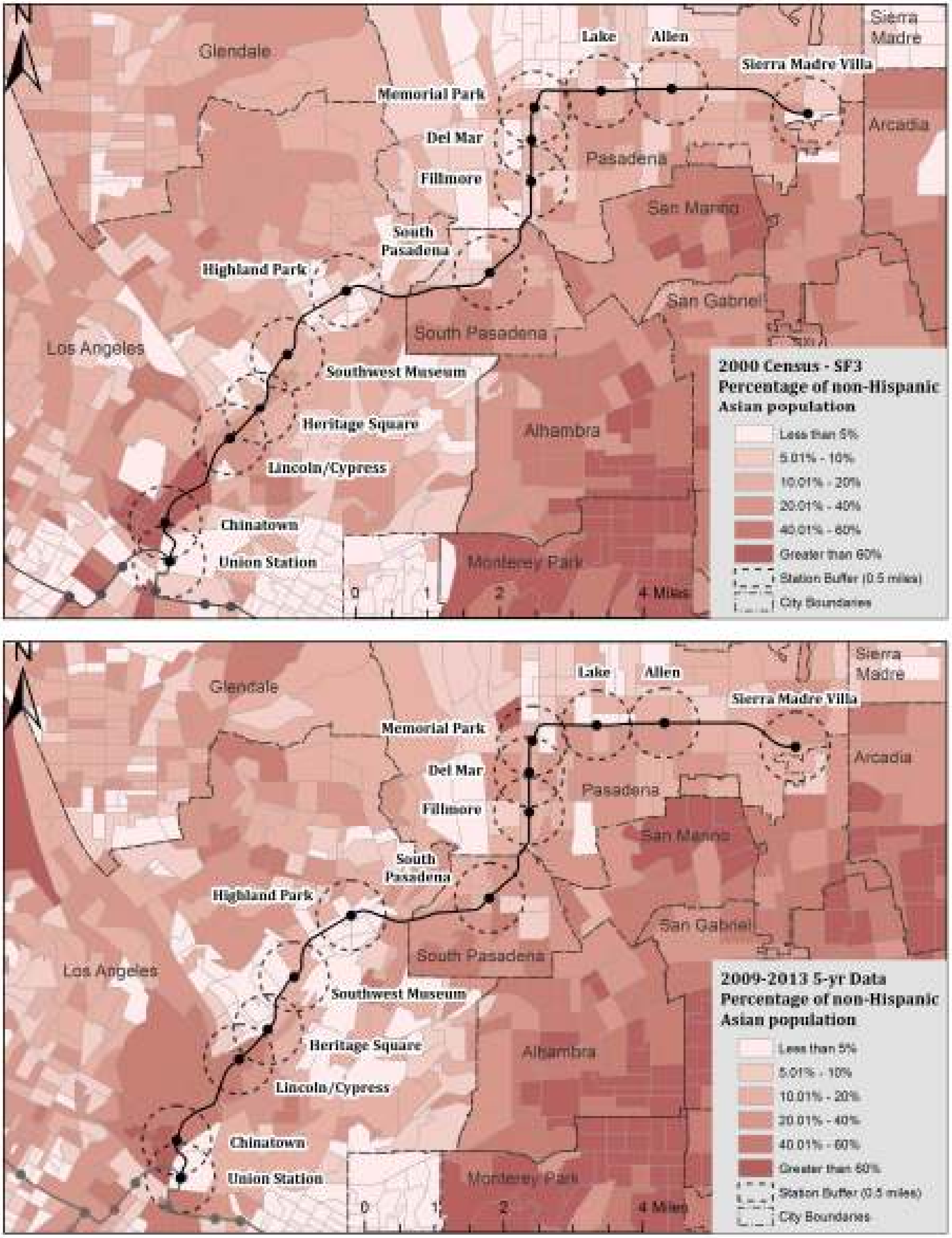

Figure 7. Percentage of non-Hispanic Asian population

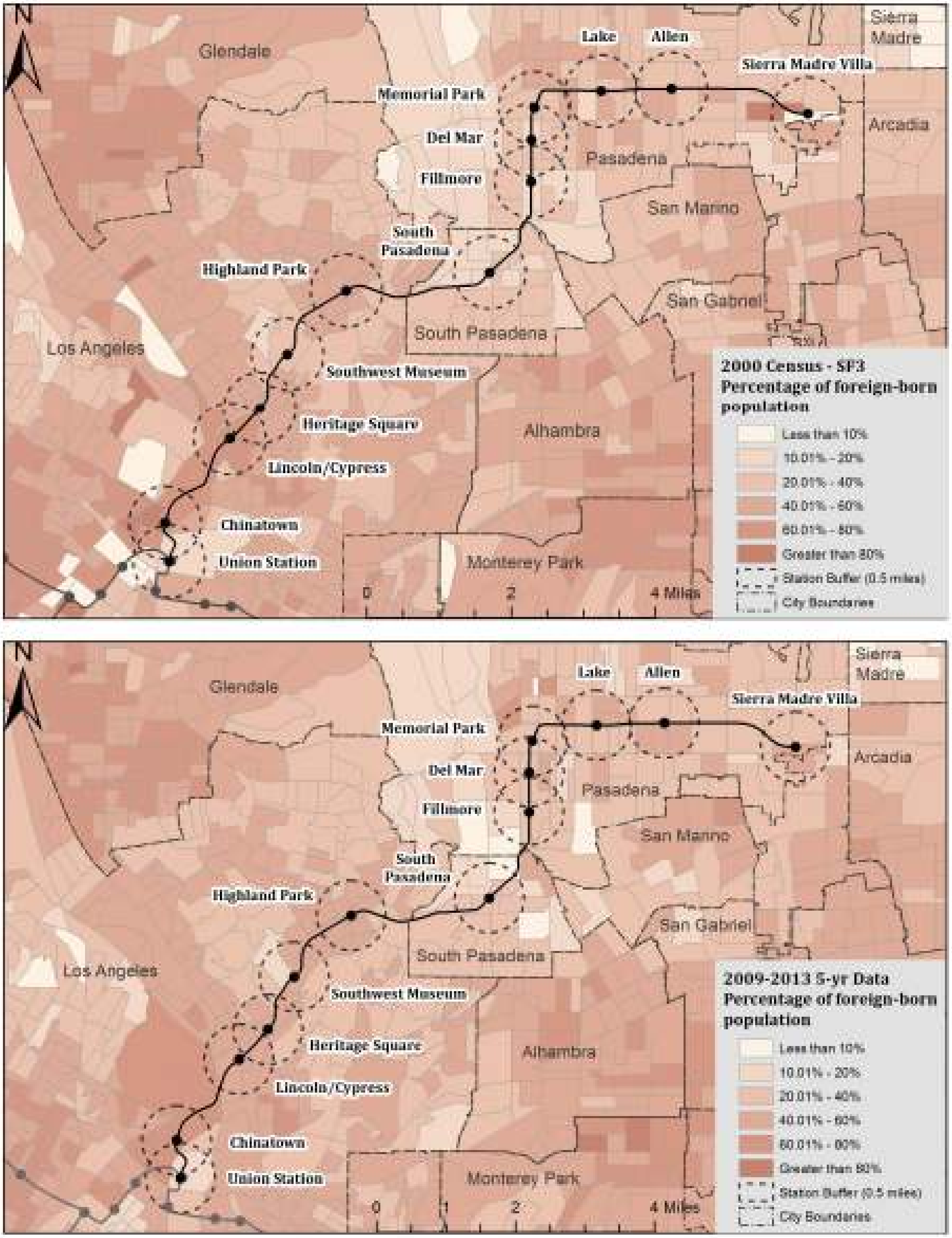

Figure 8. Percentage of Foreign-born population

III-3. Economic Characteristics

The station areas in the City of Los Angeles are generally less economically well off than those station areas in the Cities of Pasadena and South Pasadena. Figure 9 shows the median household income for the Gold Line station areas with darker colors representing higher median incomes. It appears that, overall, median household incomes rose generally throughout the region from 2000 to 2011. In both maps, however, there is a noticeable difference in median household incomes between Los Angeles and counterparts (i.e., corridor areas in South Pasadena and Pasadena, which show higher levels of income).

A similar correlation between economic wealth and geographical location is evident from Figure 10, in which the census tract-level poverty status around stations is demonstrated. A higher percentage of households below the poverty line reside in areas closer to Downtown Los Angeles (nearer to Union Station and Chinatown stations) compared to the Cities of South Pasadena and Pasadena. These areas also have relatively higher unemployment rates, while a higher degree of fluctuation is detected from 2000 to 2011 in some station areas (Figure 11).

Employment in higher paying jobs, such as those in management and professional occupations, tends to concentrate in the Cities of South Pasadena and Pasadena along the Gold Line (Figure 12). This echoes the noticeable pattern of income distribution mentioned above and a geographical concentration of highly educated people in these areas as shown in Figure 13. There are some areas adjacent to transit stations in Pasadena however, where the percentage of such higher paying employment is quite low (i.e., around Memorial Park, Lake, Allen, and Sierra Madre Villa), compared with the rest of the city. Station areas in South Pasadena and Pasadena include many locations where 40-60% of residents have at least a bachelor's degree, while station areas in Los Angeles have more areas with less than 10% of residents with at least a bachelor's degree.

It also needs to be noted that there is visible variation among station areas in their percentage of owner-occupied housing units (Figures 14). Near Downtown Los Angeles at the Union Station and Chinatown stations, there are significant areas with less than 5% owner-occupied units in 2011, while the other four Los Angeles stations have relatively higher percentages of home ownership. Memorial Park and Lake in Pasadena show lower numbers of owner-occupied housing units compared to neighboring stations in that city. Generally, there appears to be more rental units closer to the urban core of Downtown Los Angeles and closer to the Gold Line in Pasadena (Figure 15), whereas owner-occupied housing units seem to dominate areas further away from the rail line.

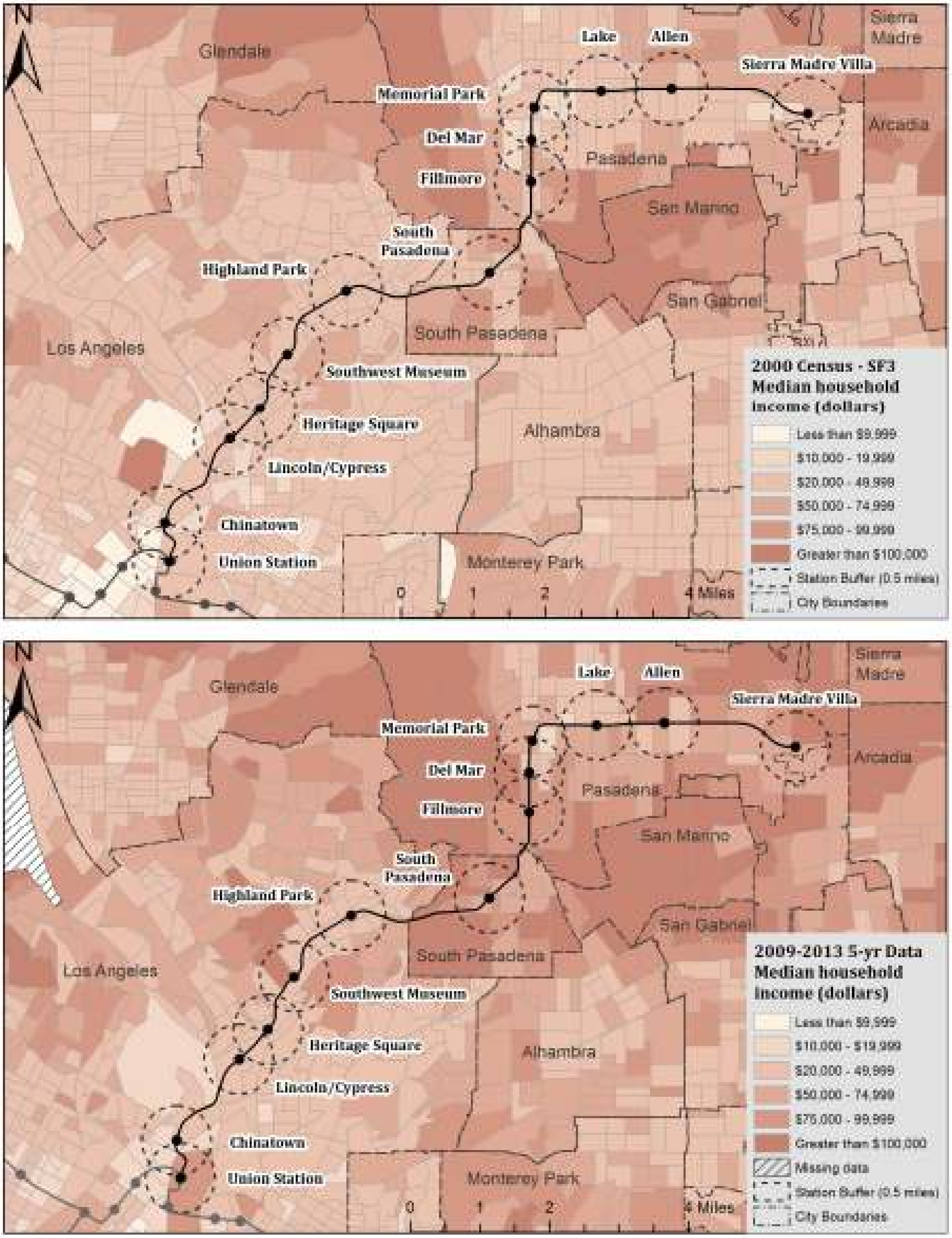

Figure 9. Median household income

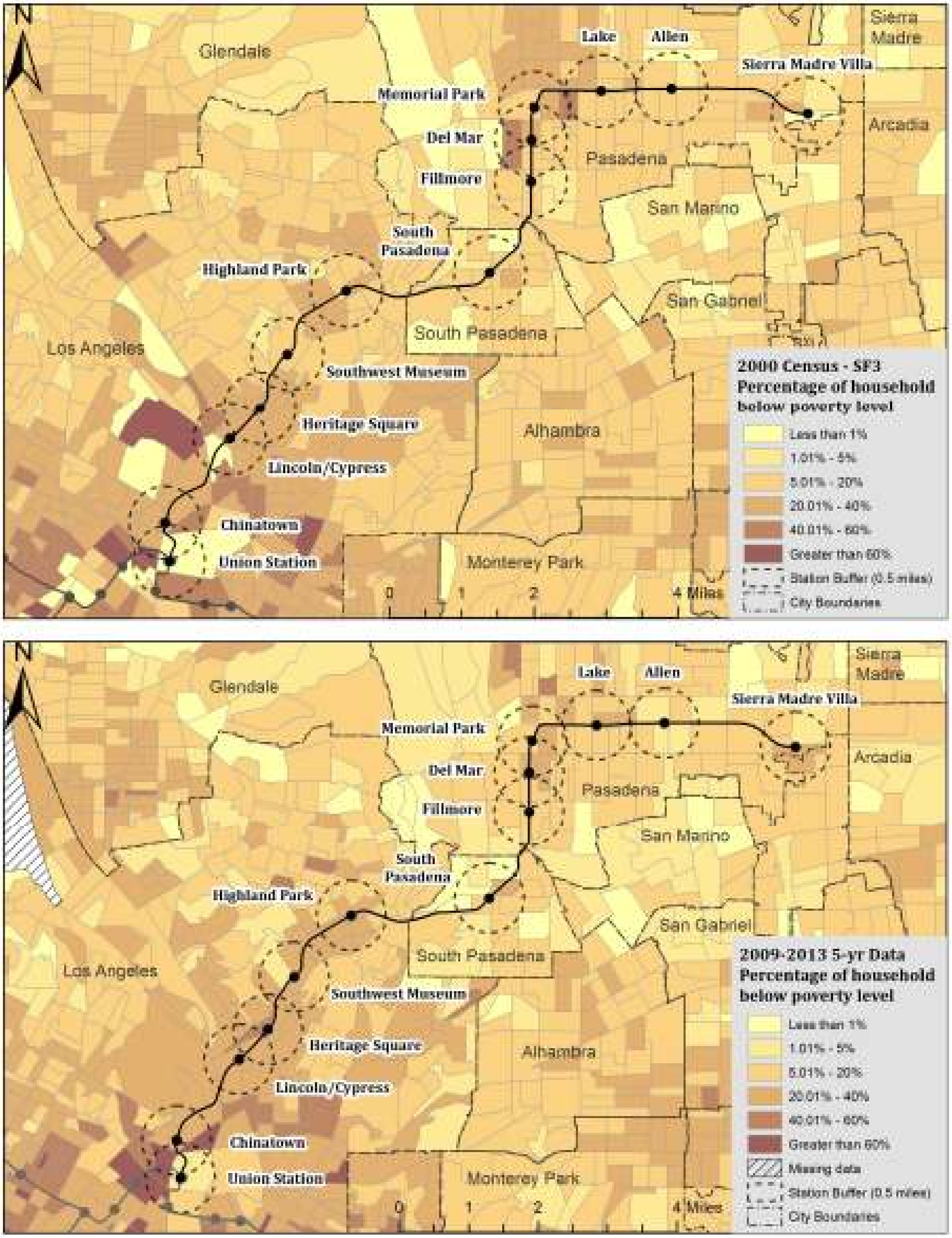

Figure 10. Percentage of household below poverty level

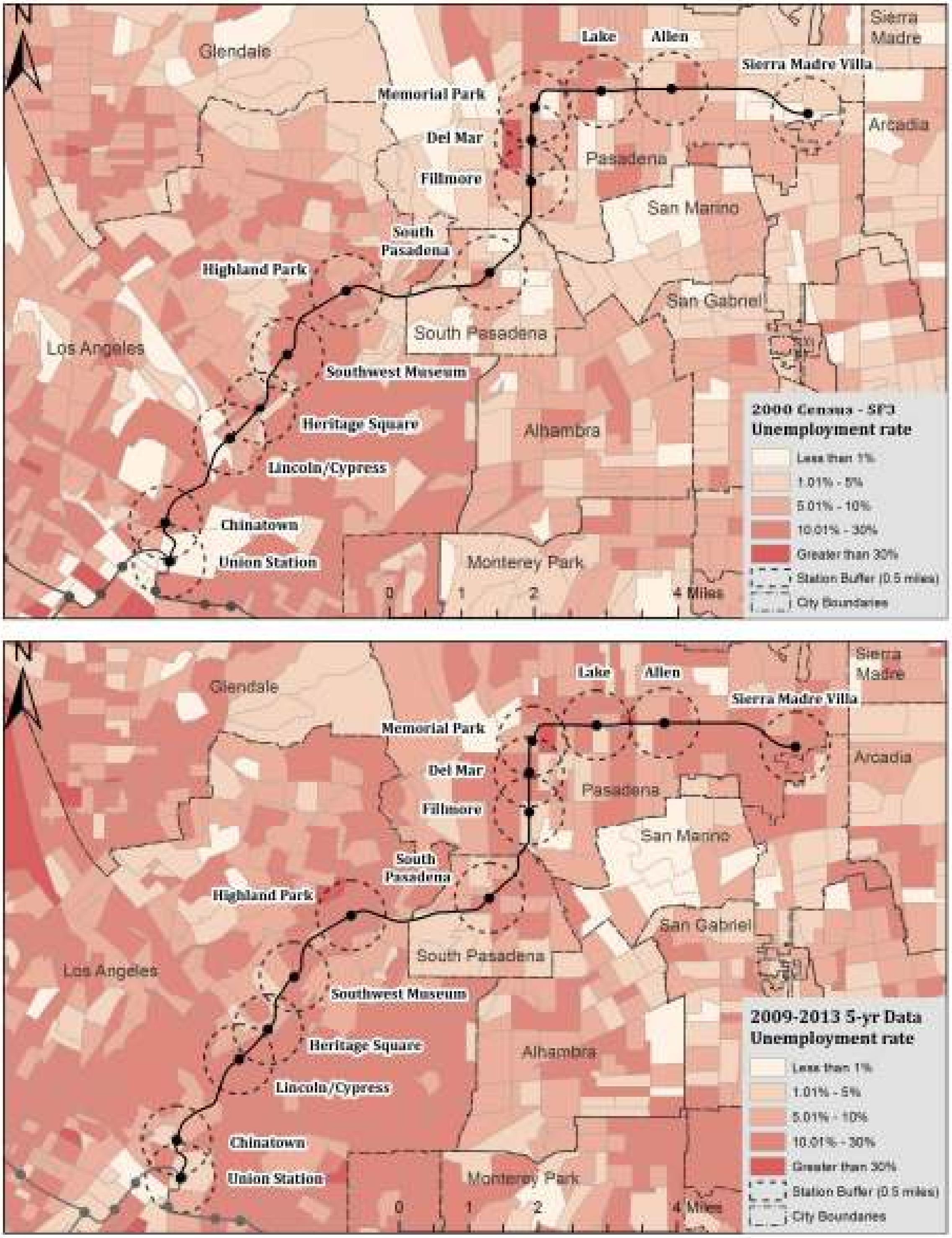

Figure 11. Unemployment rate

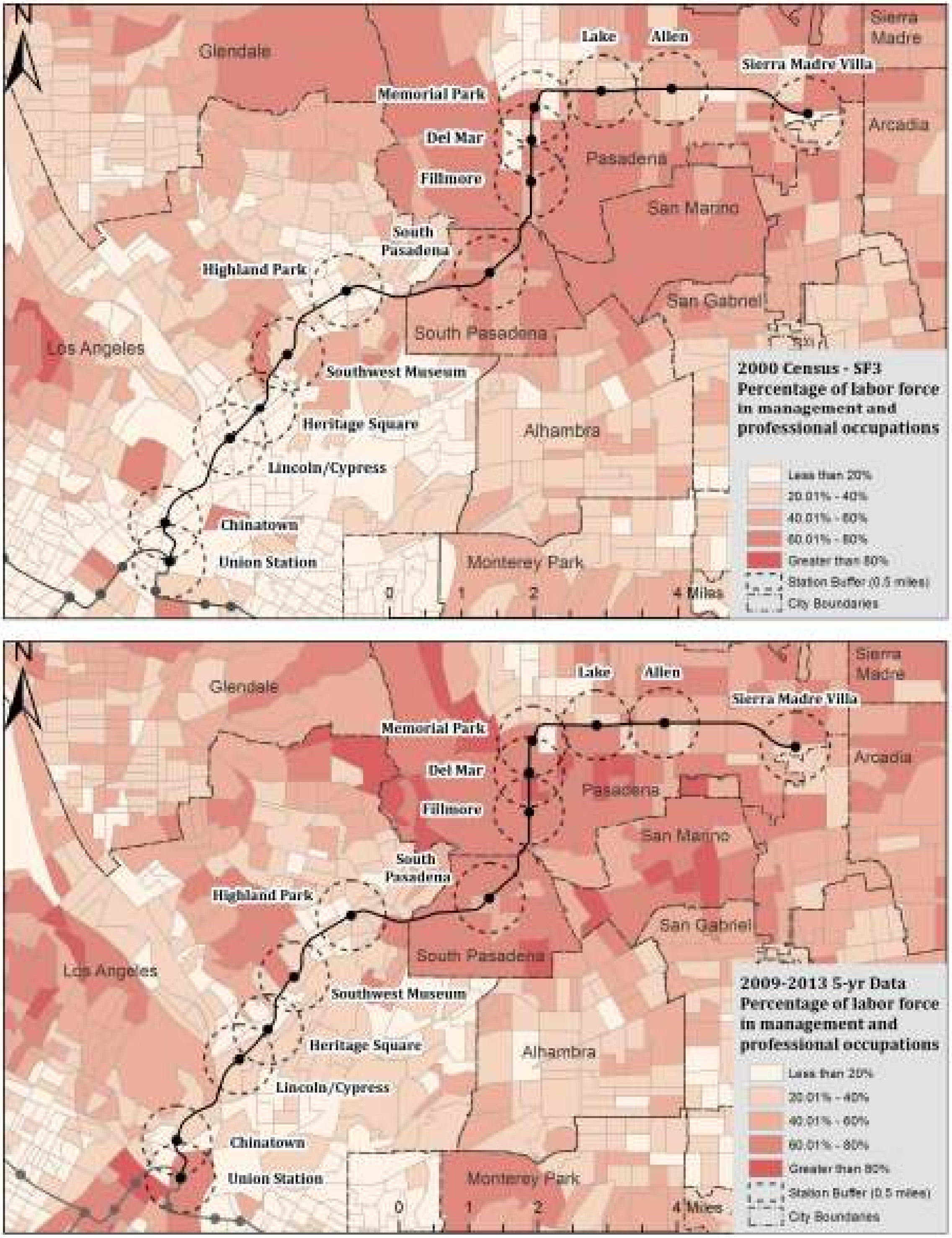

Figure 12. Percentage of labor force in management and professional occupations

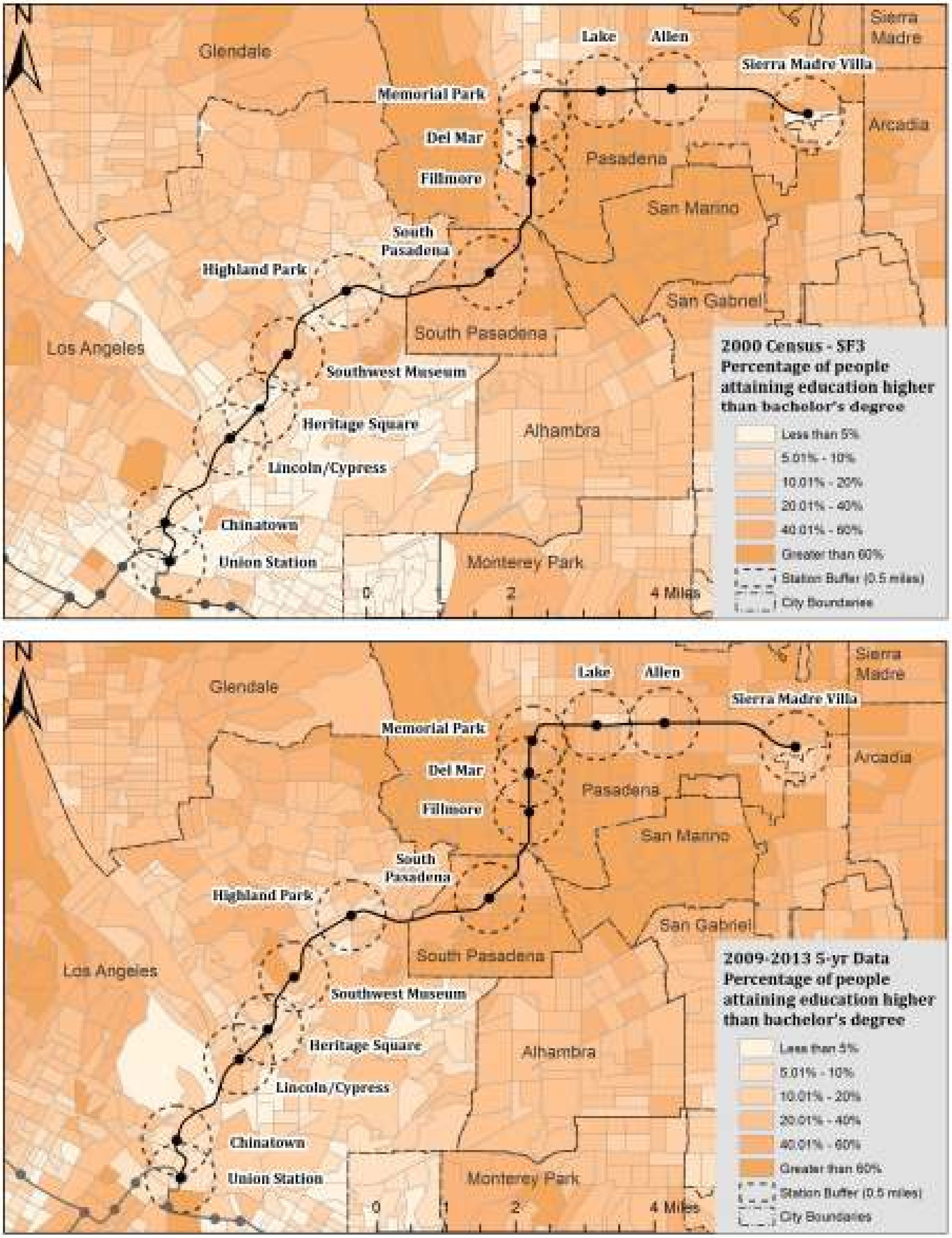

Figure 13. Percentage of highly educated population

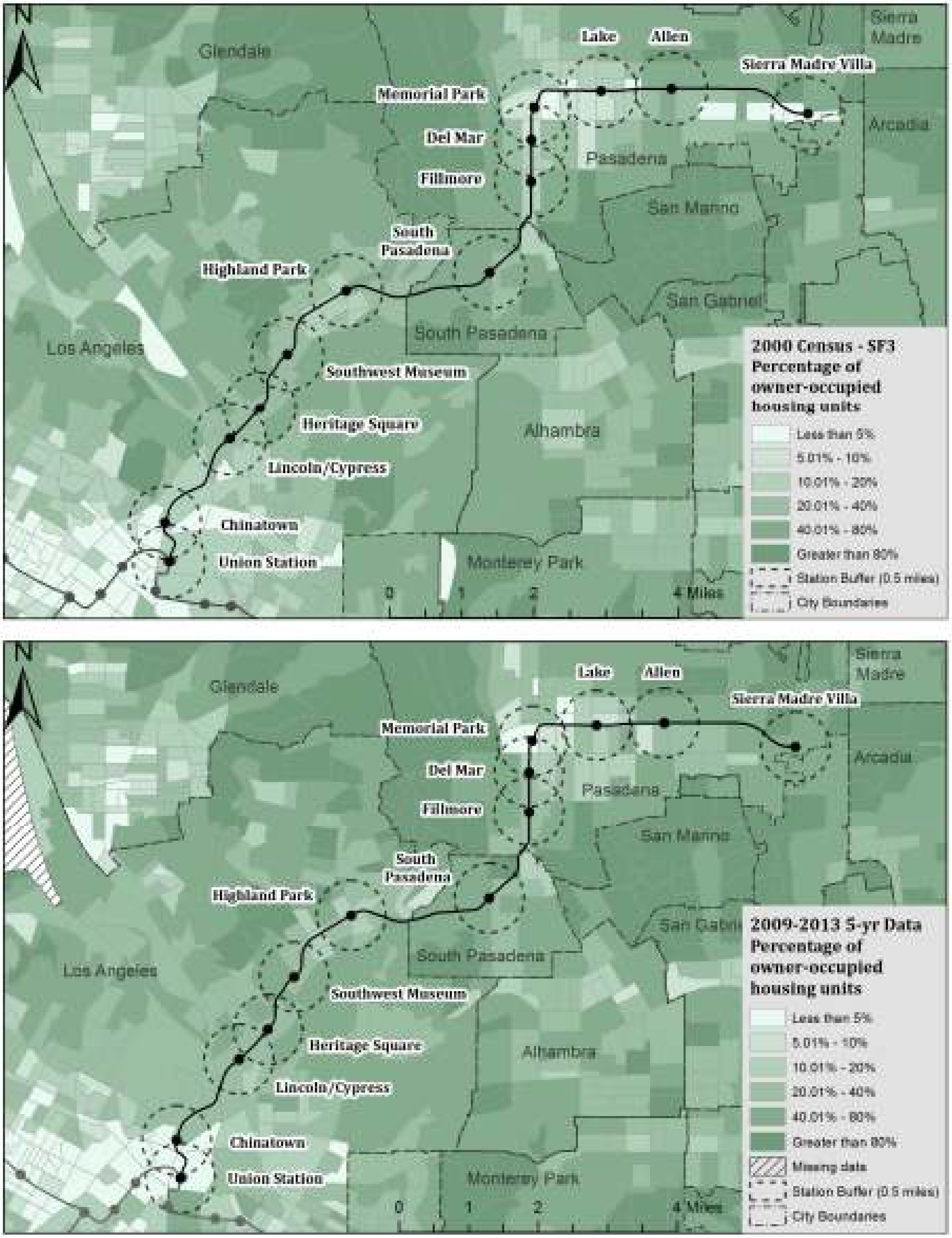

Figure 14. Percentage of owner-occupied housing units

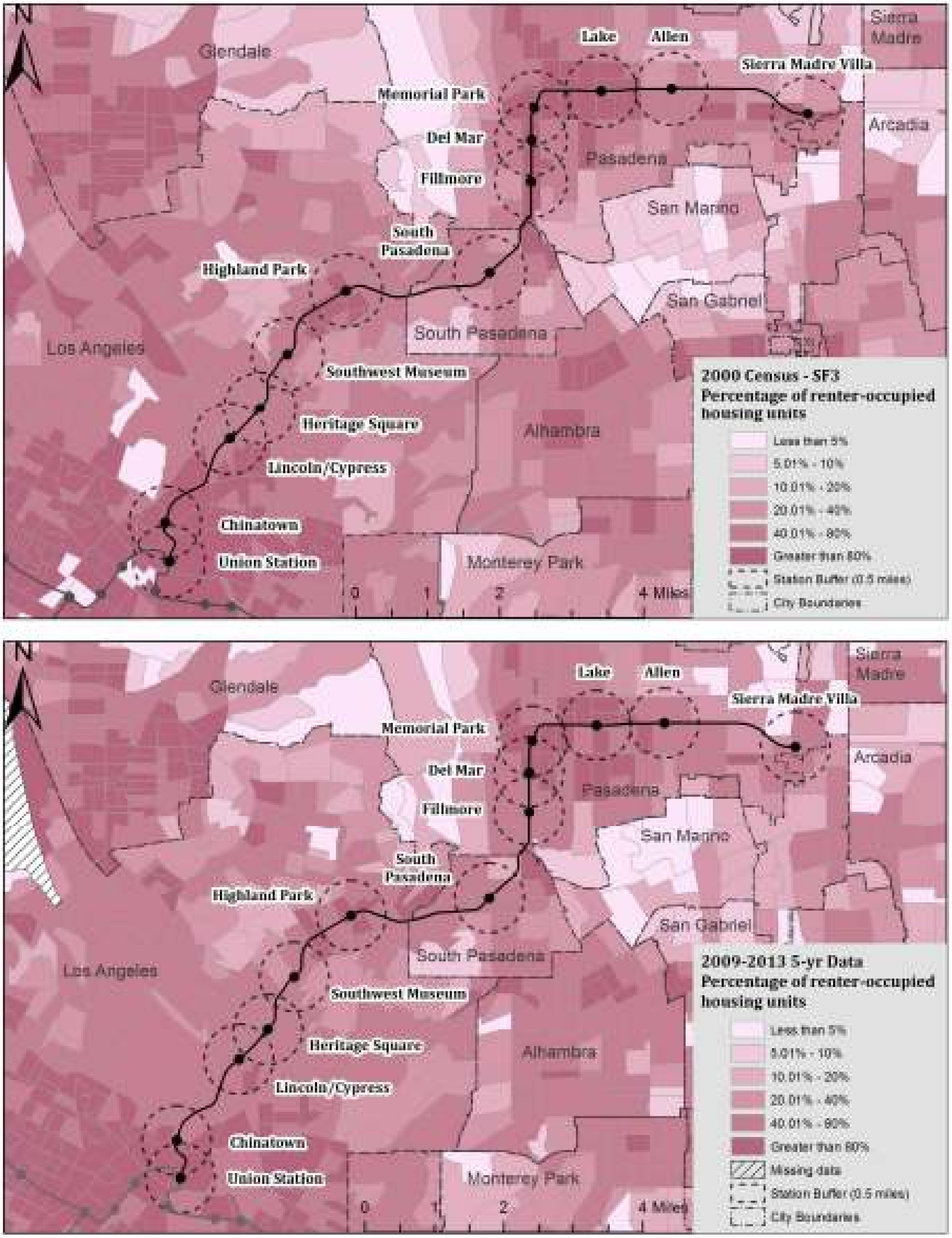

Figure 15. Percentage of renter-occupied housing units

III-4. Other Characteristics

A substantial degree of variation also exists in terms of built environments and policy attitudes. For instance, stations closer to Downtown Los Angeles were found to have a more favorable micro-level arrangement in a recent study (Elkind et al., 2015), which graded transit stations according to how well they facilitate walkability, transit use, and transit-oriented development. The Mission station in South Pasadena and the Allen and Sierra Madre Villa stations in Pasadena (which were mainly surrounded by single-family homes) received the lowest scores in the study. Table 1 provides the scores that each Gold Line Phase I station earned in the study.

Table 1. Gold Line Phase I grades

Station Name	**City**	**Grade**
Union Station	Los Angeles	B
Chinatown	Los Angeles	A
Lincoln Heights/Cypress Park	Los Angeles	A-
Heritage Square/Arroyo	Los Angeles	B-
Southwest Museum	Los Angeles	B-
Highland Park	Los Angeles	B+
Mission	South Pasadena	C-
Fillmore	Pasadena	B-
Del Mar	Pasadena	C
Memorial Park	Pasadena	C
Lake	Pasadena	B-
Allen	Pasadena	D
Sierra Madre Villa	Pasadena	C-

Data source: Elkind et al., (2015)

As noted above, the Gold Line Phase I stations are located in three different municipalities within the County of Los Angeles--Los Angeles, South Pasadena, and Pasadena--having distinct policies dealing with transit and surrounding land uses and development. Los Angeles has the most extensive collection of related policies. According to the Los Angeles Transit Corridors Strategy (Carlton et al., 2012), which contains a comprehensive review of TOD-related policies, the City of Los Angeles has more than ten planning documents containing policies related to TOD. These include design guidelines, General Plan elements, Specific Plans, bike plans, and others. Metro also has two programmatic documents that relate to TOD in Los Angeles. Despite this wealth of TOD policies, a research consultant team led by UC Berkeley that conducted the review for Metro, points out that actual implementation of TOD around stations in Los Angeles has been somewhat limited. Notable exceptions exist, however, with Metro joint development around stations, some redevelopment, and public infrastructure projects (Carlton et al., 2012).

The City of South Pasadena uses its General Plan and the Mission Street Specific Plan to promote transit-oriented land uses around the Gold Line. The Mission Street Specific Plan was adopted in 1996 and provided incentives to developers to catalyze an area in anticipation of the opening of the Gold Line transit service. One strategy used by the plan was to list parcels that would qualify for density bonuses if developed as mixed-use or residential properties near the Gold Line.

The City of Pasadena's TOD-related policies exist in their General Plan and Specific Plans around stations. The draft General Plan mobility element (currently being updated) calls for mixed-use zoning, transit friendly features, and multi-family and affordable housing in transit corridors. Also, four Specific Plans in Pasadena surround transit stations and deal with them specifically. The Central District Specific Plan, for example, contains within its boundaries four Gold Line Stations and promotes the development of 'transit villages' with high density housing around the stations. Figure 16 shows specific plans surrounding stations along the Gold Line, which have been used as a key instrument to promote TOD.

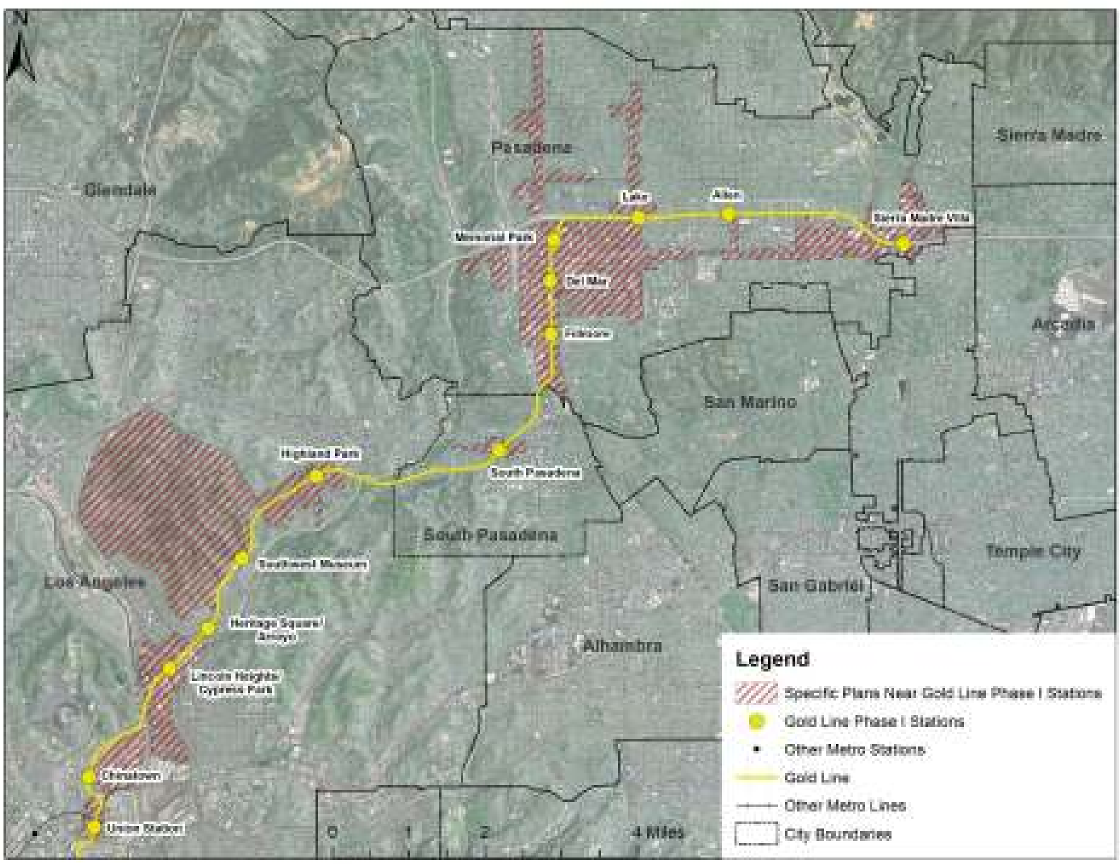

Figure 16. Map of specific plans

IV. Explorative Analysis

IV-1. Methodology

Before investigating the impacts of transit investment on land use change dynamics, an exploration is made of the patterns of parcel-level land use changes in the study region. For this explorative analysis, we extensively use the SCAG's current land use data, combined with the LACMTA rail station shapefile. The SCAG data file contains longitudinal land use information of approximately 2 million land parcels in Los Angeles County for the years 1990, 1993, 2001, 2005, 2008, and 2012. Each parcel is identified by the SCAG's unique land use coding scheme, having nearly 140 types of detailed land use. We group the detailed land uses into 15 categories, as shown in Table 2, and investigate how land use composition has evolved over time in the study region.

Table 2. Land use classification (15 categories)

No.	Category	SCAG Land Use Codes
1	Single-family Residential	111*
2	Duplex & Townhouses	1122
3	Multi-Family Residential	112* except 1122
4	Other Types of Residential	110*, 113*, 114*, 115*
5	Commercial & Services	120*, 121*, 122*, 123*
6	Industrial	130*, 131*, 132*, 133*, 134*
7	TCU Facilities [a]	140*, 141*, … , 145*, 146*
8	Public Facilities [b]	124*, 125*, 126*, 127*
9	Mixed Developed	150*, 160*
10	Open Space and Recreational	180*, 181*, … , 187*, 188*
11	Urban Vacant & Under Construction	170*, 190*
12	Agricultural	200*, 210*, 211*, 212*, 220*, … , 260*, 270*
13	Non-Urban Vacant	310*, 320*, 330*, 340*
14	Water and Water Facilities	400*, 410*, …, 440*, 450*
15	Undetermined	0, 128*, 129*, 888*, 999*

[a] TCU stands for Transportation, Communication, and Utilities; [b] Public Facilities include land parcels for military purposes as well as schools and government offices.

More specifically, consideration is given to the following geographical boundaries of interest:

1. Entire county (i.e., Los Angeles County)
2. Transit station vicinities (0.5-mile radius)
    a. near all stations
    b. near Gold Line Phase I stations opened in 2003
    c. near old stations opened before Gold Line Phase I
    d. near newer stations opened after Gold Line Phase I

3. Policy areas
    a. Federal Renewal Community Initiative (FRCI) areas[2]
    b. Federal Empowerment Zones (FEZ)[3]
    c. State Enterprise Zones (SEZ)[4]
    d. Los Angeles County's 2005 TOD layer[5]
    e. Los Angeles' Business Improvement Districts (BID)[6]
    f. Los Angeles' Targeted Neighborhood Initiative (TNI) areas[7]
4. Overlapping areas in which each of the above six polices and transit proximity (0.5-mile radius) are combined geographically (see Figure 17).

To understand land use distribution changes more effectively, we also calculate the Herfindahl-Hirschman Index (HHI) for each data year, as shown below.

$$HHI = \sum_{i=1}^{15} s_i^2$$

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[2] To reduce unemployment and foster economic growth in blighted communities, the U.S. Department of Housing and Urban Development introduced this initiative in 1993 (for more detailed information, see http://portal.hud.gov/hudportal/HUD?src=/program_offices/comm_planning/economicdevelopment/programs/rc). The Community Renewal Tax Relief of 2000 supported qualifying businesses in the communities by providing employment credits and tax exempts. We acquire the policy layer that indicates the designated communities from the City of Los Angeles' open data website. These areas include seven rail transit stations in Los Angeles.

[3] Similar to FRCI, this program aims to improve the economic conditions of highly distressed communities with a series of federal incentives. The FEZ areas are mostly located along the Blue and Gold Lines.

[4] The SEZ program was originated from the Enterprise Zone Act (AB 40) and the Employment and Economic Incentive Act (AB 514) in 1984, and was established by SB 2023 and AB 296 in 1996 (Assembly Jobs, Economic Development, and the Economy Committee, 2010). The main purpose is to encourage business investment in declining areas through incentives, such as business groups hiring credits, longer net operating loss carryforward period, and the allowance of accelerated depreciation (Assembly Jobs, Economic Development, and the Economy Committee, 2010).

[5] The LA County's TOD program is aimed at encouraging active and sustainable transportation modes and facilitating economic activities through infill, compact, and mixed developments (Los Angeles County, 2007). The 2005 layer includes six TODs around Hawthorn, Vermont, Willowbrook, Slauson, Florence, and Firestone stations.

[6] This program was introduced to the City of Los Angeles in 2003. The BID implementation has been regarded as a notable example of collaborations between public and private agencies (Cook and MacDonald, 2011). The BID boundaries (obtained from the City of Los Angeles' website) show that some of the districts are located near public transit stations. For instance, the South Park BID overlaps with the 0.5-mile vicinity of Pico Station, while the Figueroa Corridor BID is associated with Grand/LATTC (Los Angeles Trade-Technical College), LATTC/Ortho Institute, Jefferson/USC, EXPO Park/USC and EXPO/Vermont stations.

[7] This initiative was created to revitalize marginal neighborhoods in the city with Community Development Block Grants. More specifically, the TNI aimed to make capital improvements and housing rehabilitation through the implementation of a group of programs, including micro-loans, community enhancement rehabilitation loans, and homeownership down payment assistance programs (City of Los Angeles, n.d., http://planning.lacity.org/cwd/gnlpln/HsgElt/HE/Ch2Bkgnd.htm).

where s_i represents the share of each of the fifteen land use category (in terms of the parcel count). A higher value of HHI (maximum=1) indicates that the area is dominated by one or fewer land use types, whereas a lower value indicates a more diverse land use composition.

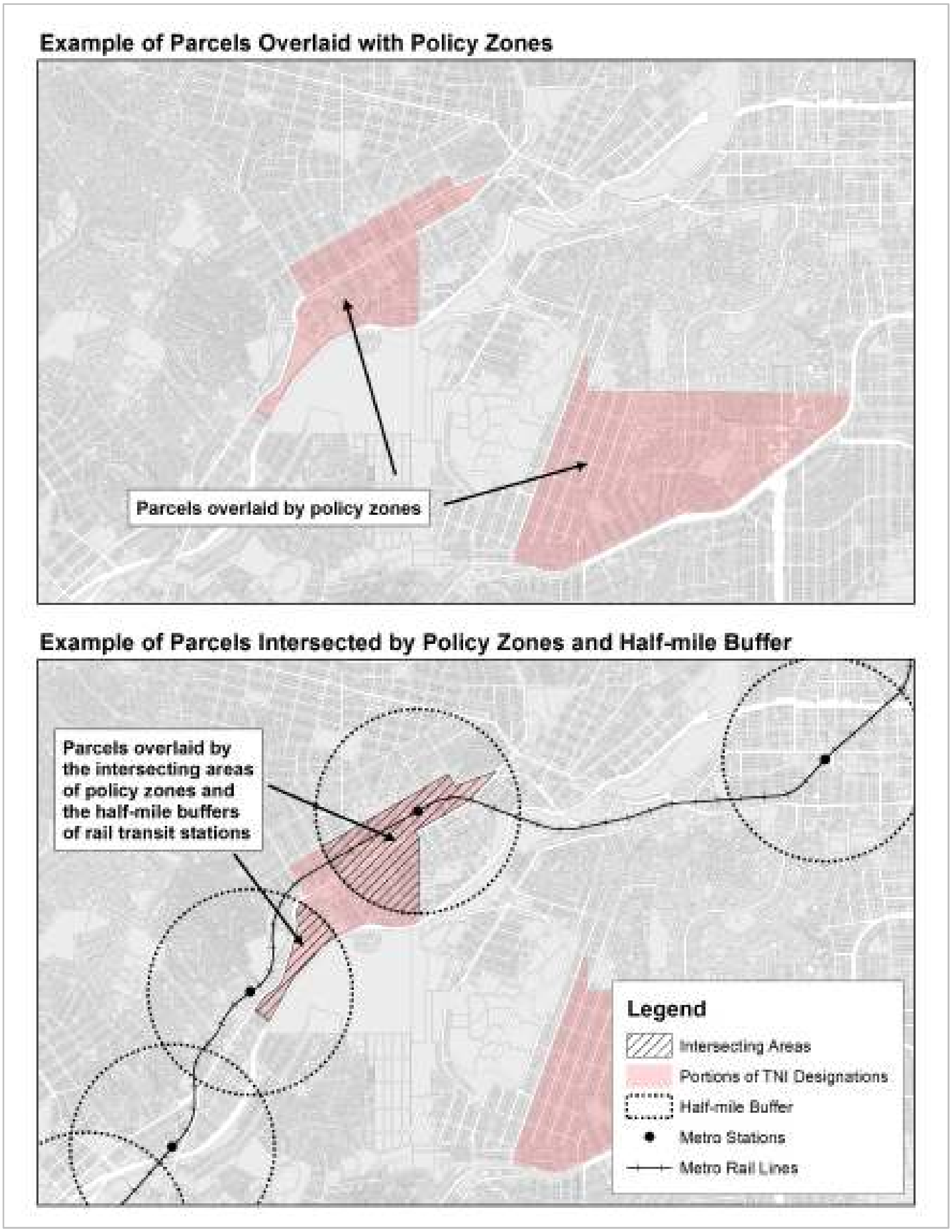

Figure 17. Overlapping policy areas and transit vicinity boundaries

IV-2. Results

Figure 18 shows the evolution of land use composition in Los Angeles County, as a whole. More than 65% of the parcels in the county are used for single-family residential uses. While the percentage of duplex and townhouses shows a substantial increase from 2001 to 2012, more compact multi-family residential areas have not expanded (in terms of parcel counts as opposed to housing units), suggesting that the overall residential land use has not intensified significantly in the county. However, the ratio of vacant parcels (including urban vacant, under construction, and non-urban vacant) has declined significantly, suggesting that new (infill) development has taken place in the county.

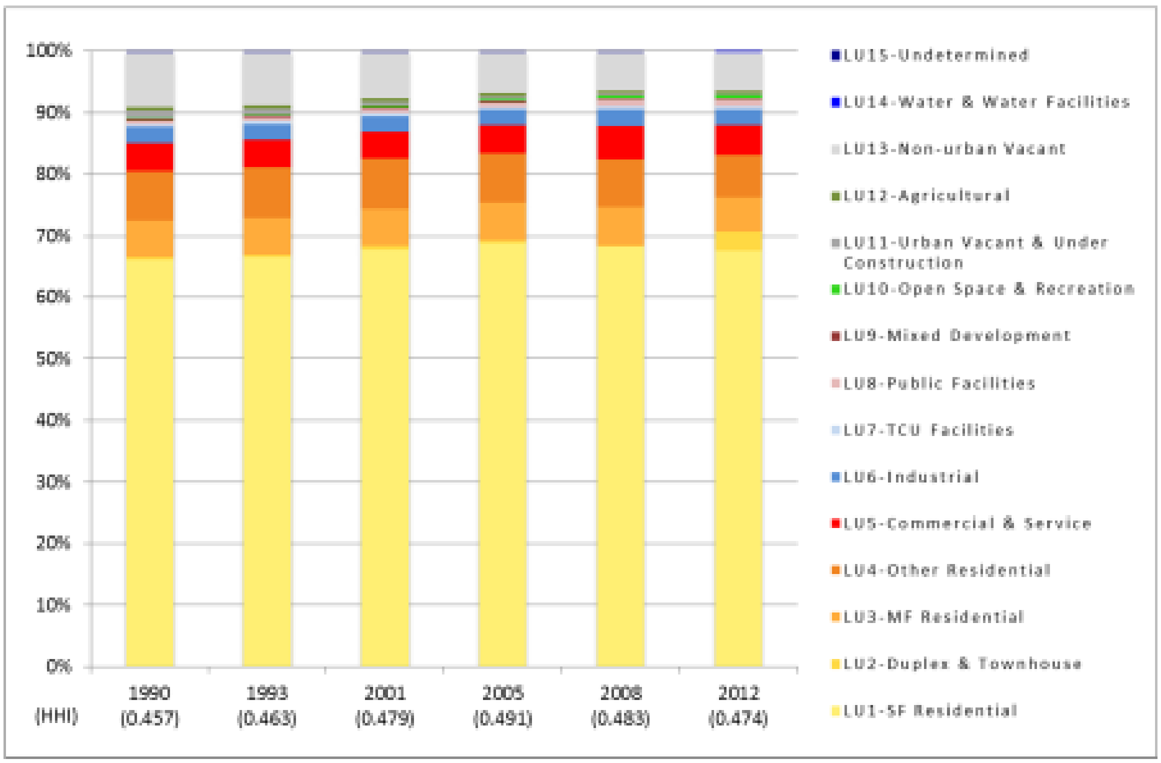

Figure 18. Land use composition, 1990-2012 (Los Angeles County)

Areas in the county near transit (within 0.5-mile boundaries around stations) have a distinct pattern of land use, compared to county-wide patterns (Figure 19a). The share of single-family residential is much lower (less than 40%, in terms of parcel counts) in these areas, while a larger proportion of the parcels around transit stations are designated for duplexes, townhouses, or other types of multi-family housing units. In the vicinities, the proportion of commercial land use is much larger than that in the entire county, indicating a more compact and diverse use of land near transit stations. The declining trend of HHI values (from 0.224 in 1990 to 0.204 in

2012) also suggests that the land use composition in near-transit areas has been getting more mixed.

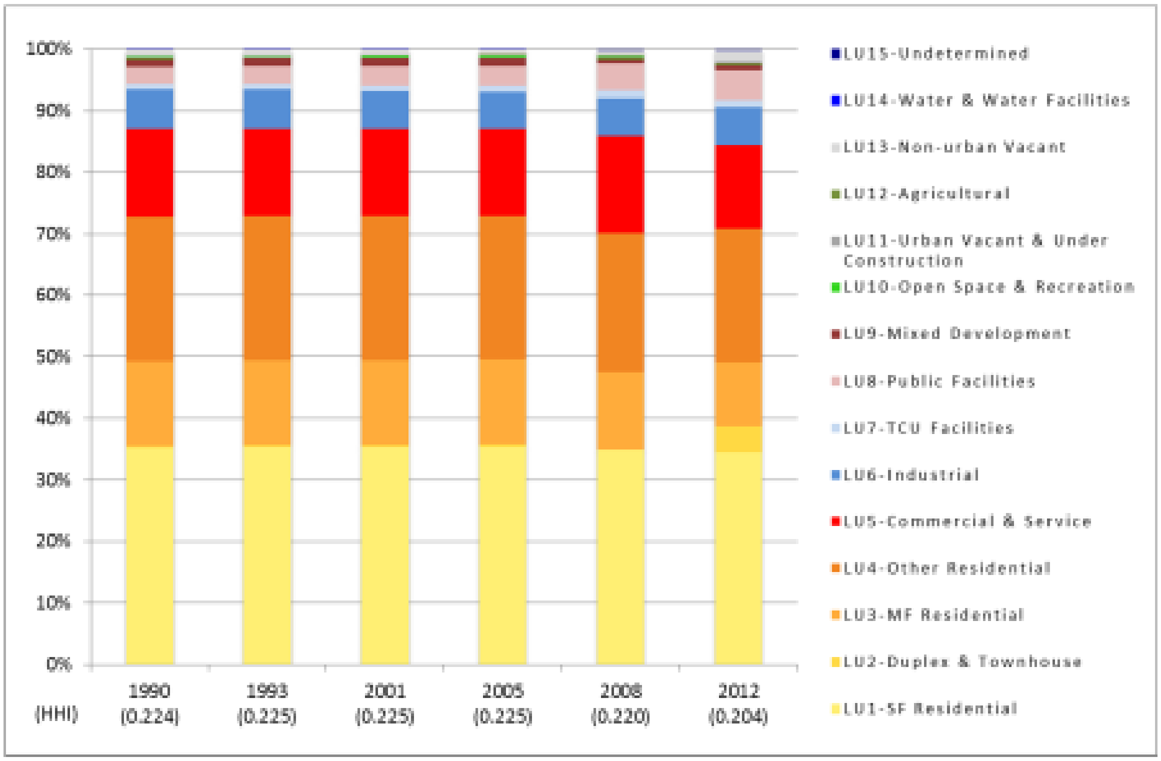

Figure 19a. Land use composition, 1990-2012 (Rail transit vicinity)

Some additional patterns of land use are detected when we classify the transit vicinities into three sub-categories based on the development timing of the nearest station (i.e., near the Gold Line Phase I stations opened in 2003; near the old stations opened before Gold Line Phase I; and near the newer stations opened after Gold Line Phase I) and analyze the trajectory of land use composition in each sub-category (Figures 19b, 19c, and 19d). The decrease in HHI values around the Gold Line Phase I stations (from 0.235 in 2001 to 0.207 in 2012) suggests that land use in these areas has become more diversified after the Gold Line Phase I opening in 2003 (Figure 19b). However, the degree of land use mix is found to be higher in the areas around the stations developed earlier (Figure 19c). Furthermore, these near-old-station areas also show a relatively higher percentage of multi-family housing units (approximately +3~4 percentage points), while the share of single-family residential is lower than the average of the entire transit vicinity. In contrast, it appears that the parcels adjacent to newer stations opened after Gold Line Phase I tend to be developed at a lower intensity with a much smaller proportion of multi-family residential land, while the share of land for commercial and service uses has increased recently (Figure 19d).

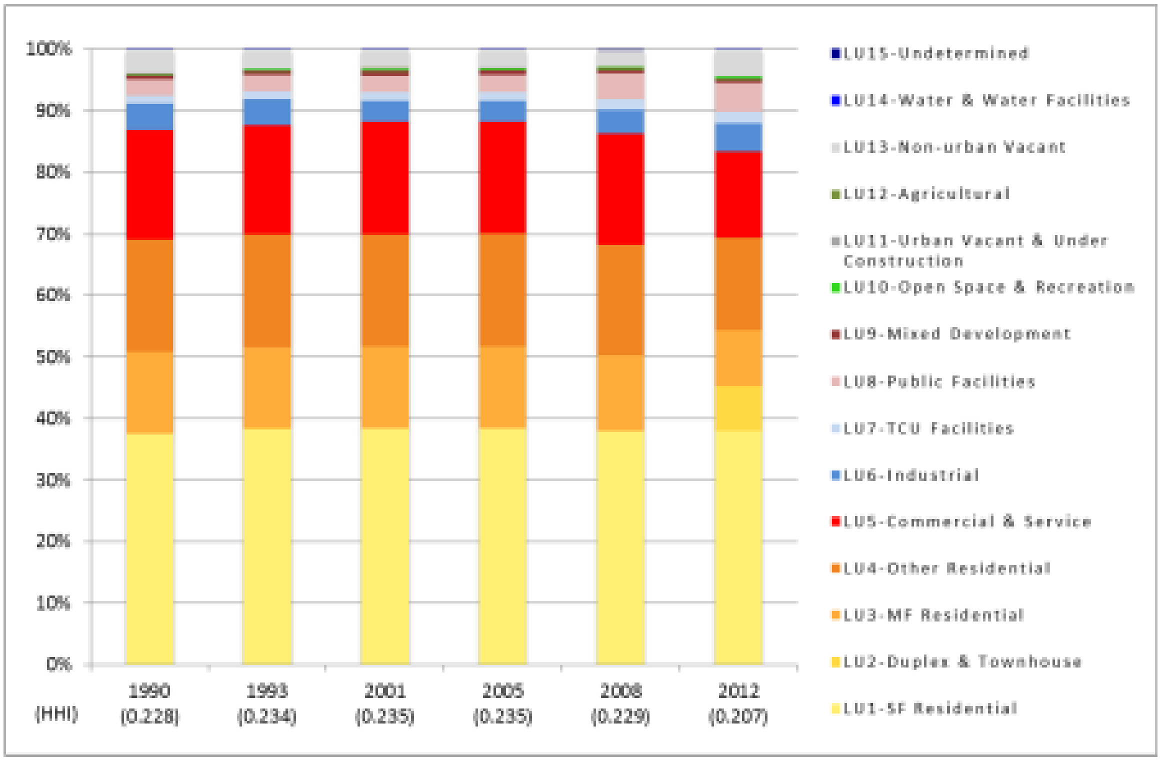

Figure 19b. Land use composition, 1990-2012 (near Gold Line Phase I stations)

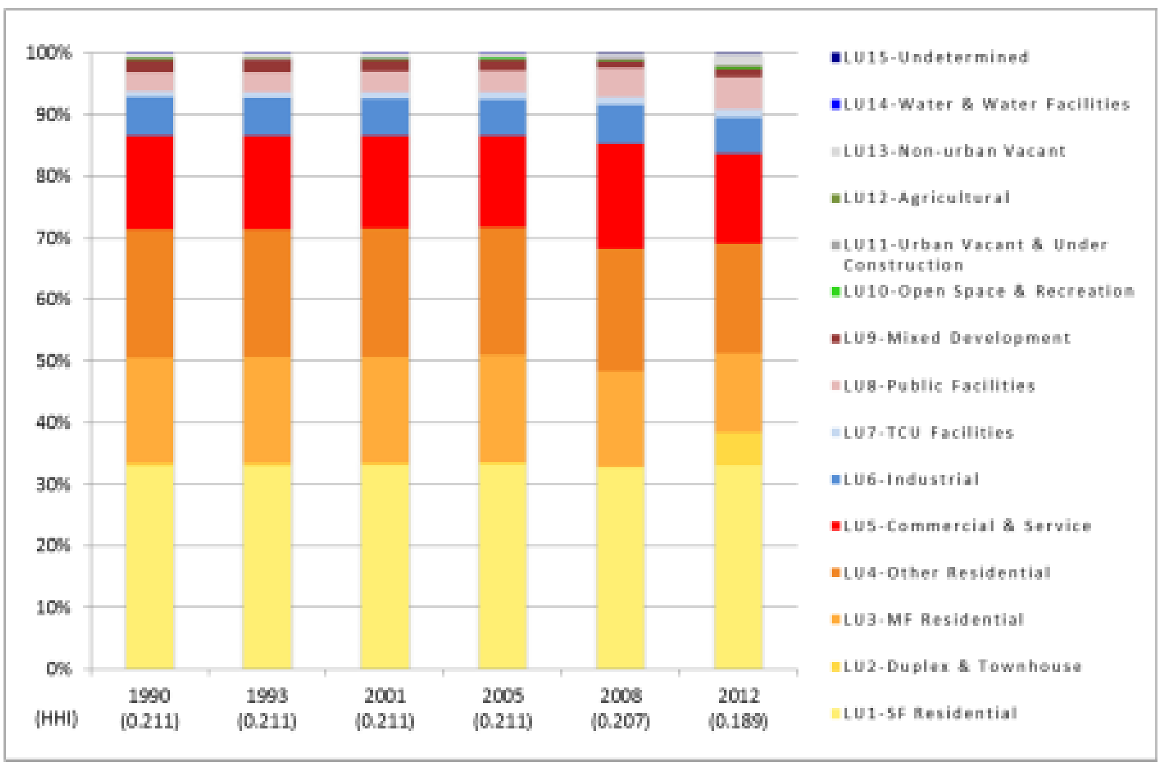

Figure 19c. Land use composition, 1990-2012 (near stations opened before Gold Line Phase I)

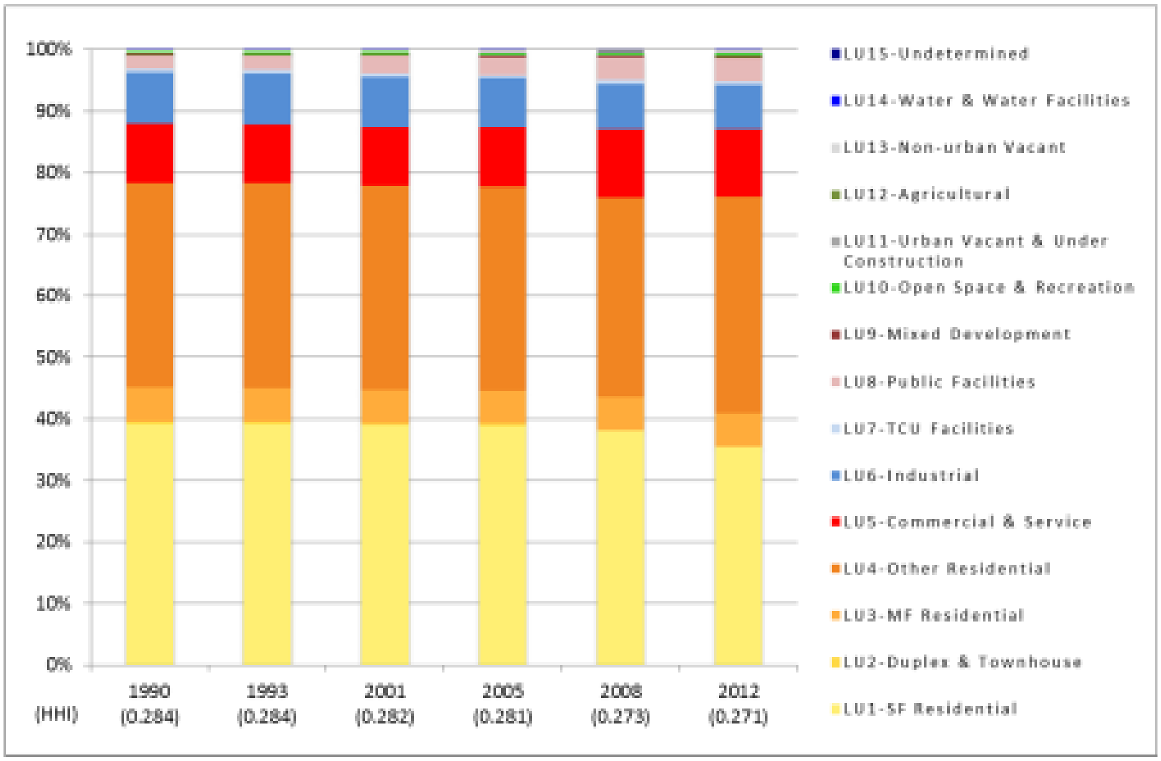

Figure 19d. Land use composition, 1990-2012 (near stations opened after Gold Line Phase I)

Figures 20a through 20f show the patterns of land use transitions in each of the six selected policy areas that are expected to facilitate a certain type of urban land development, while land use change patterns in overlapping areas (i.e., policy zones overlapped with the 0.5-mile radius transit vicinities) are presented in Figures 21a through 21f. Consistent with our expectations, a majority of BID areas are used for commercial and industrial uses, and the share of these land uses has gradually increased over the past 20 years (Figure 20e). However, the BIDs overlapped with transit vicinity show a relatively smaller percentage of commercial and industrial land and have a higher proportion of public facilities (Figure 21e). In addition, the SEZ areas are found to be somewhat dominated by residential land. While the proportion of the land used for commercial and public facility purposes has increased, industrial land has shrunken in the enterprise zones (Figure 20c). Parcels included in the 2005 TOD boundaries areas are primarily residential (approximately 80%), and the land use composition does not seem to change drastically in these areas (Figures 20d and 21d).

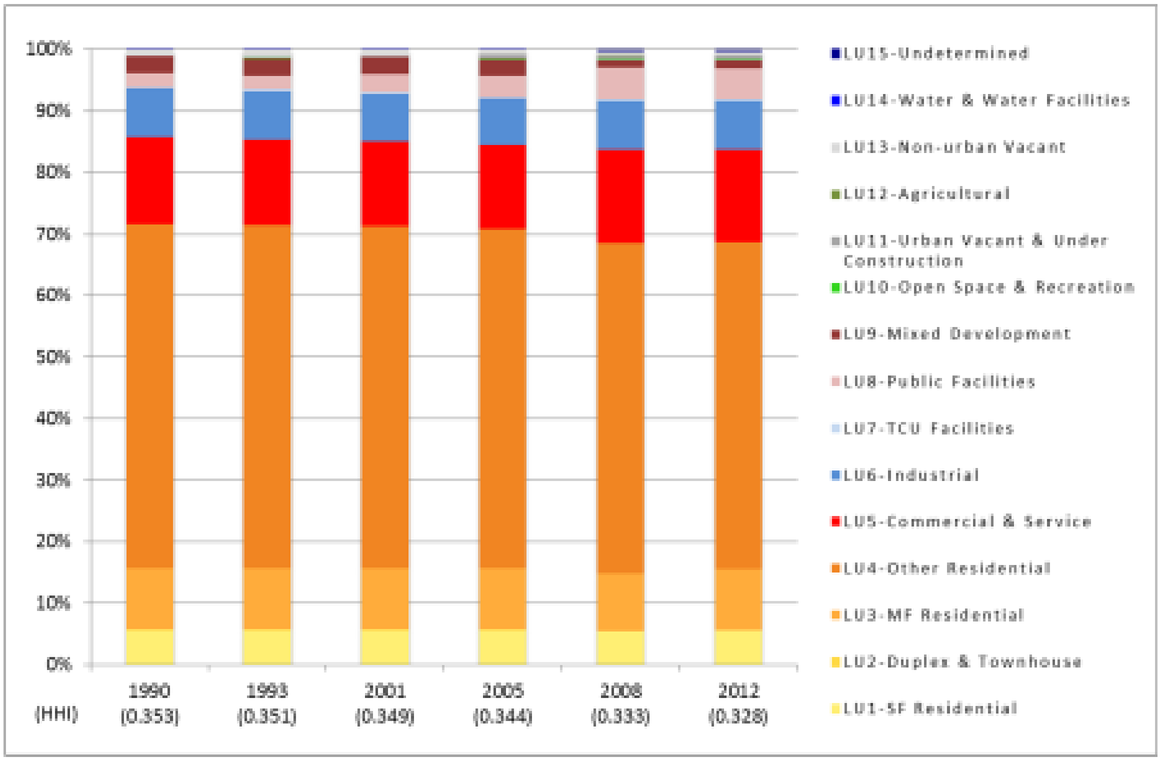

Figure 20a. Land use composition, 1990-2012 (FRCI)

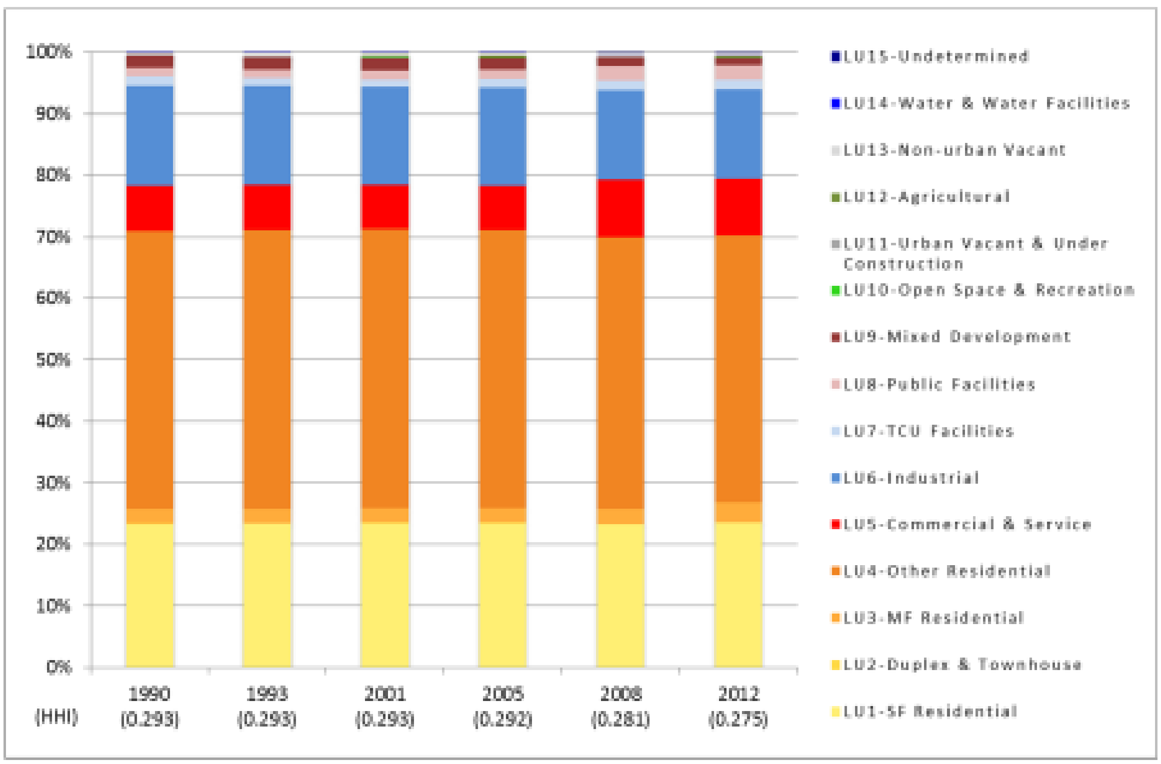

Figure 20b. Land use composition, 1990-2012 (FEZ)

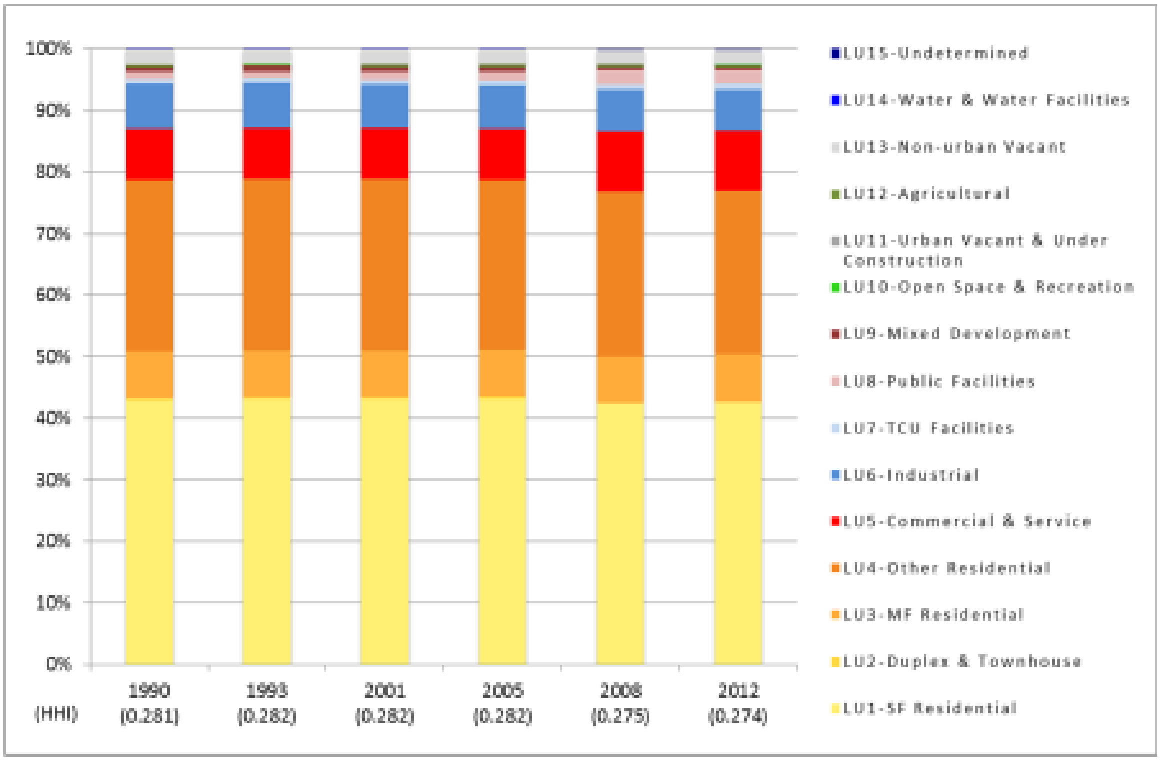

Figure 20c. Land use composition, 1990-2012 (SEZ)

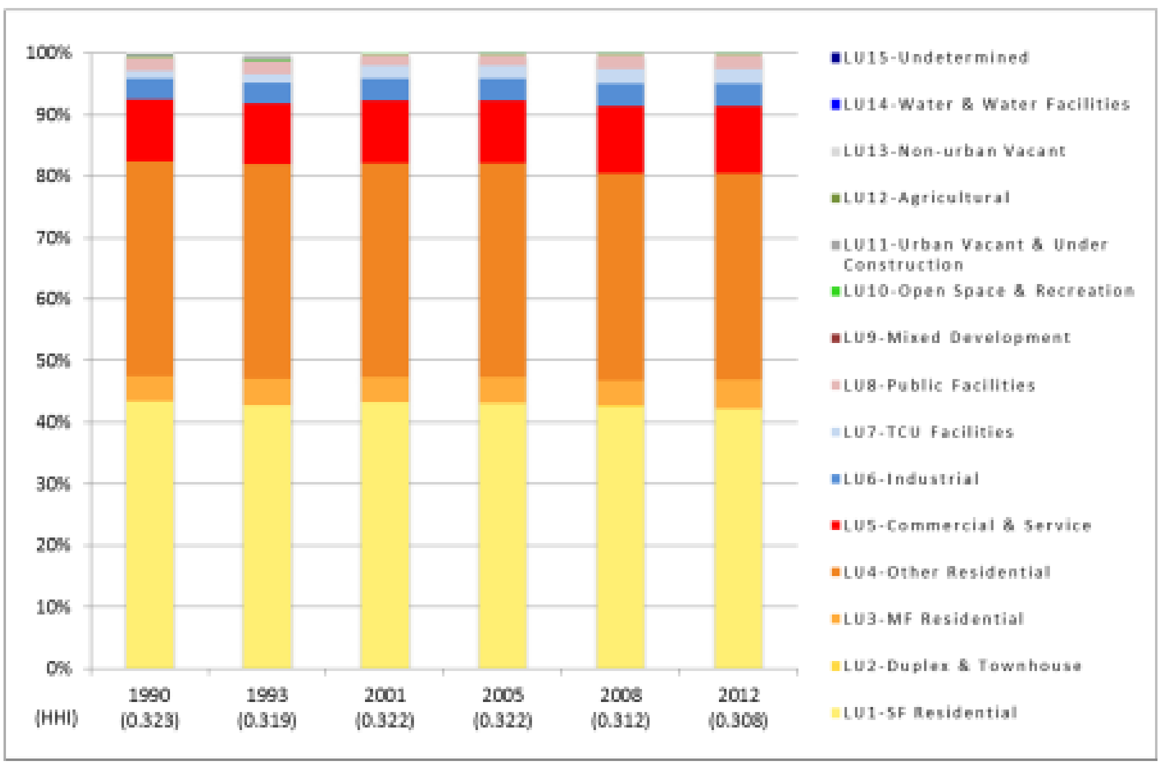

Figure 20d. Land use composition, 1990-2012 (TOD)

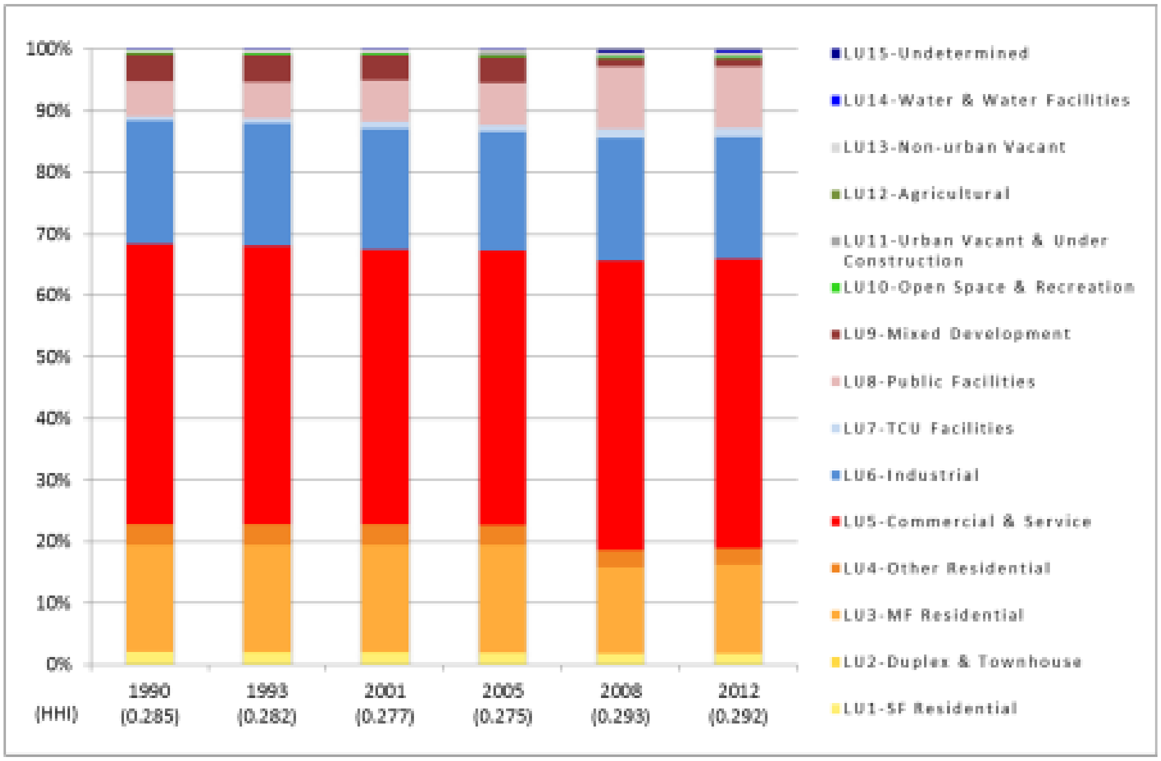

Figure 20e. Land use composition, 1990-2012 (BID)

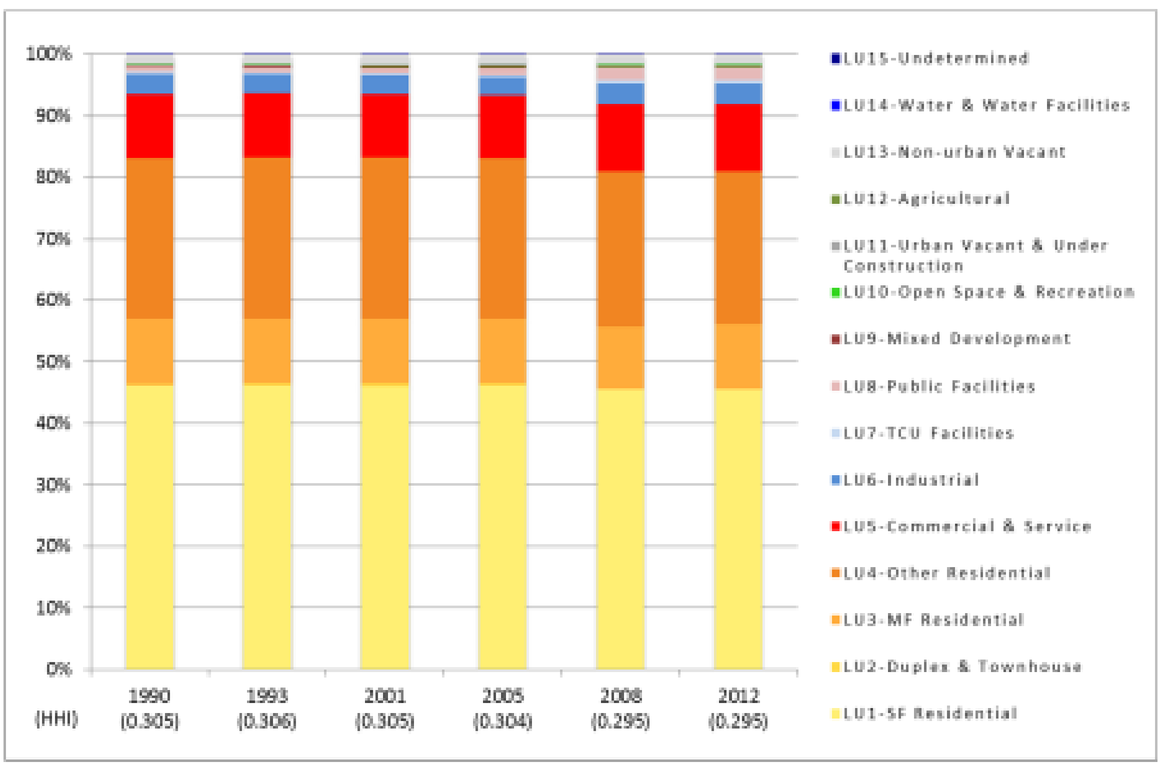

Figure 20f. Land use composition, 1990-2012 (TNI)

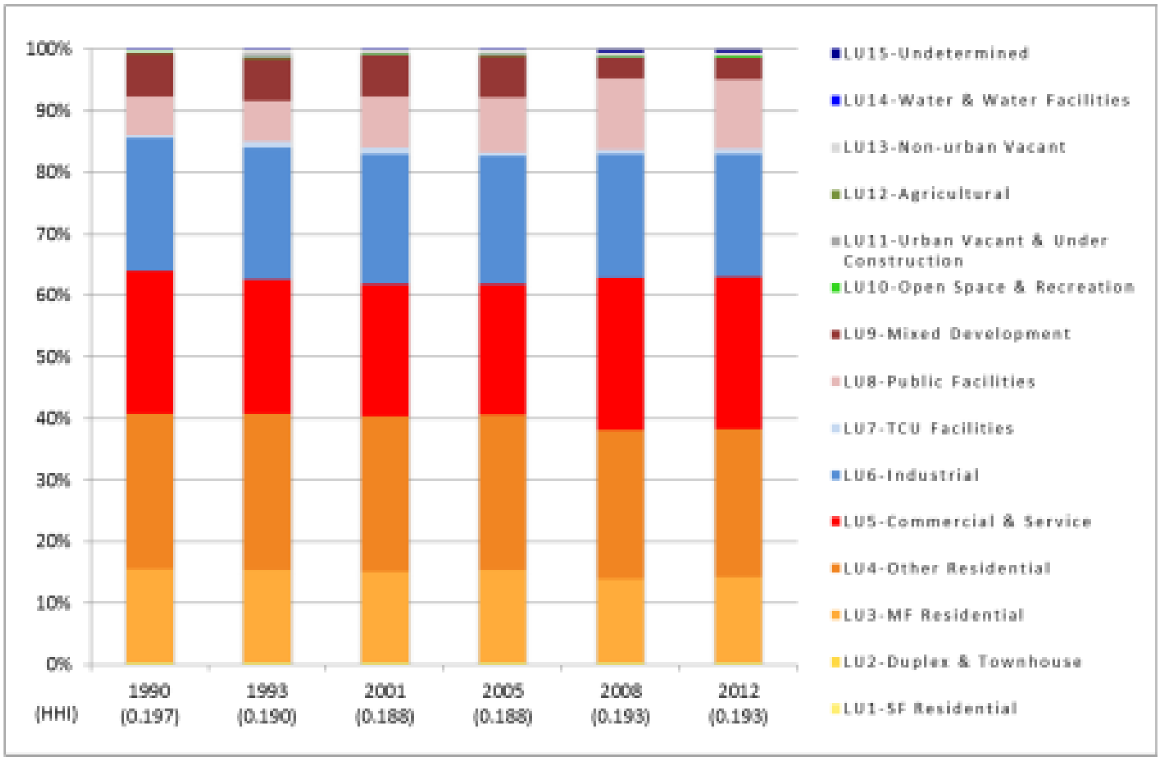

Figure 21a. Land use composition, 1990-2012 (FRCI & Transit vicinity)

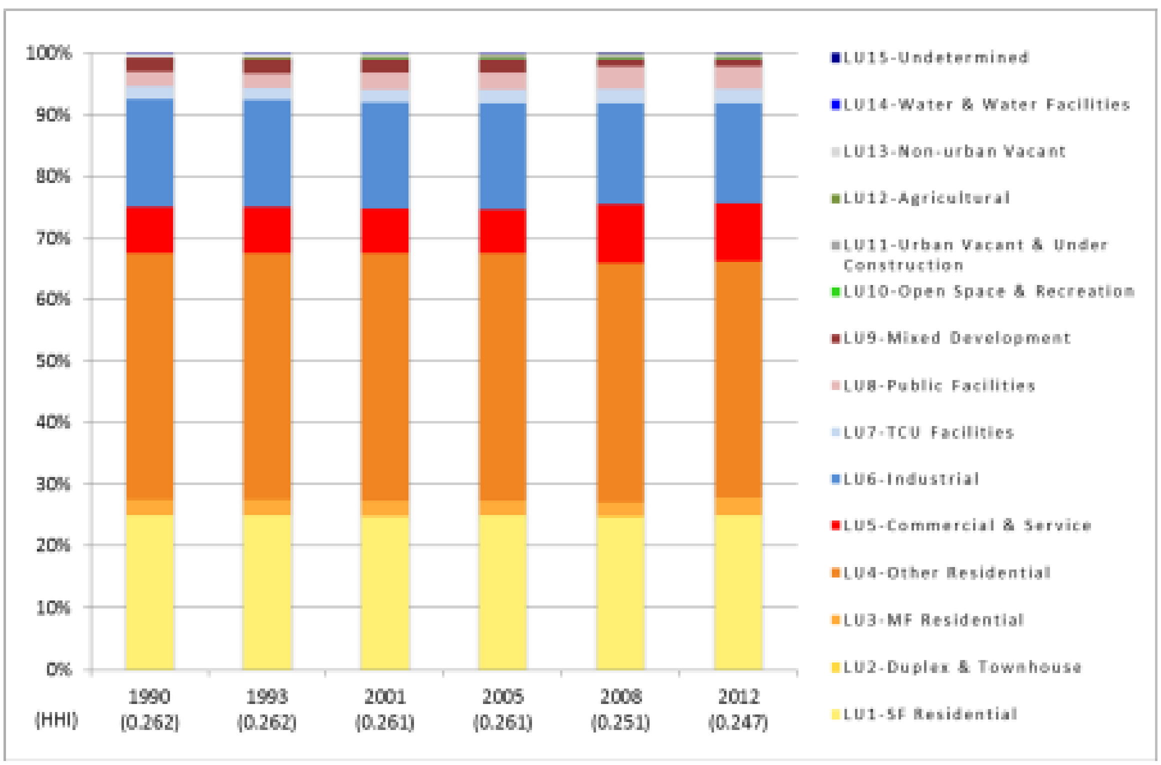

Figure 21b. Land use composition, 1990-2012 (FEZ & Transit vicinity)

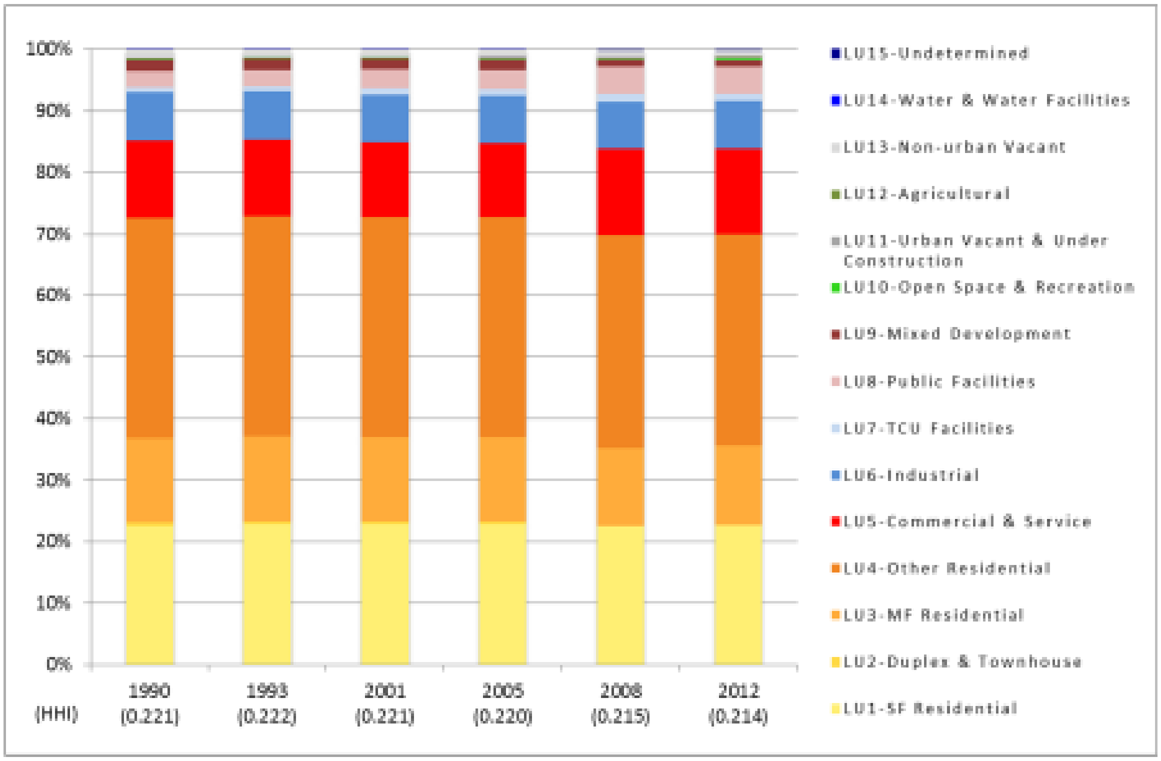

Figure 21c. Land use composition, 1990-2012 (SEZ & Transit vicinity)

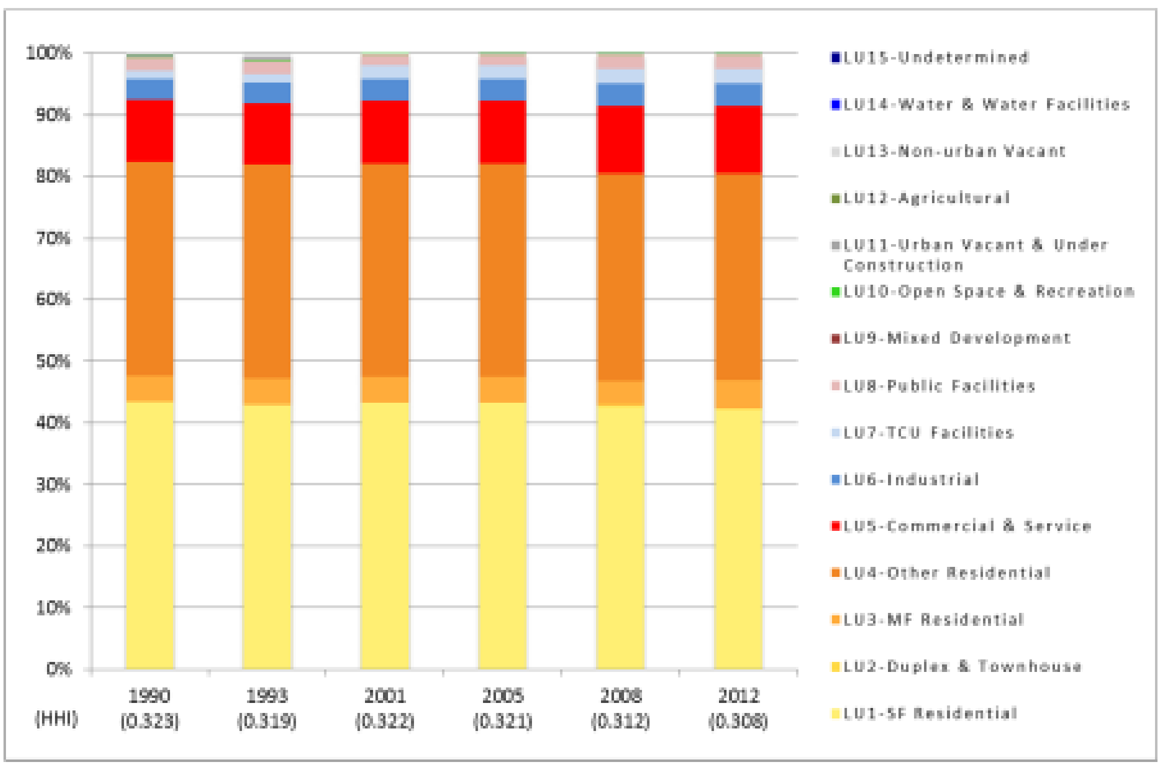

Figure 21d. Land use composition, 1990-2012 (TOD & Transit vicinity)

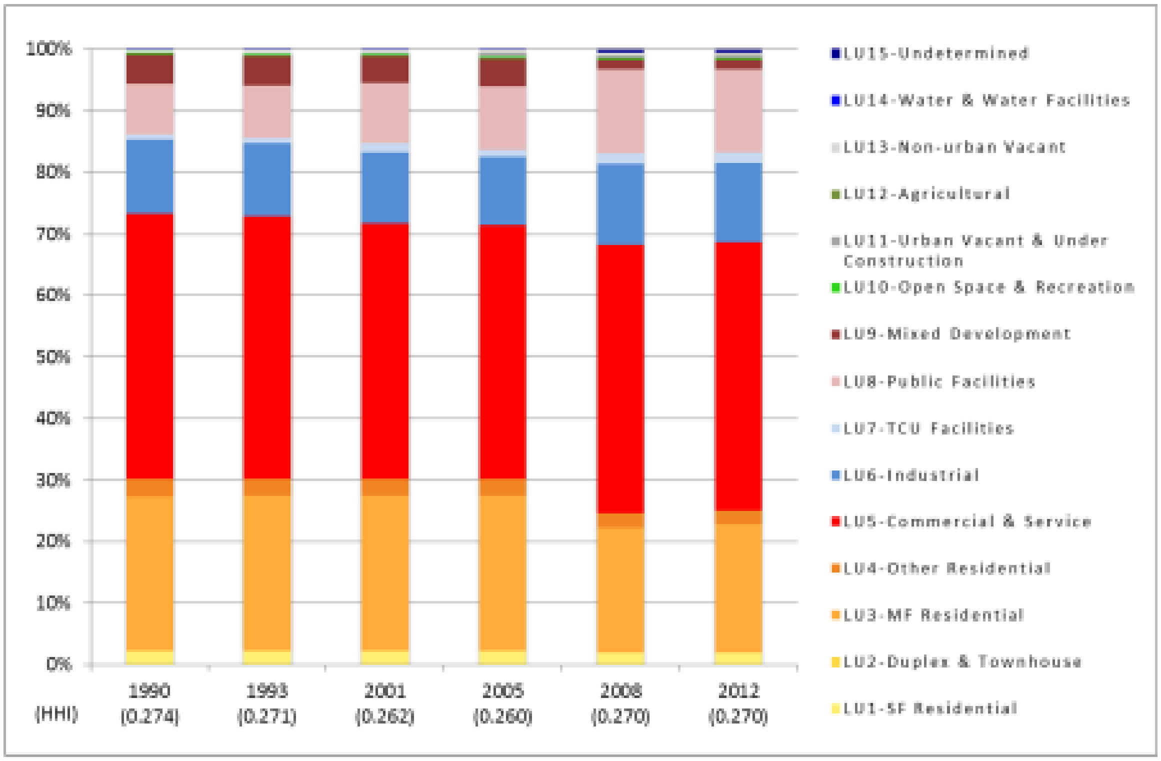

Figure 21e. Land use composition, 1990-2012 (BID & Transit vicinity)

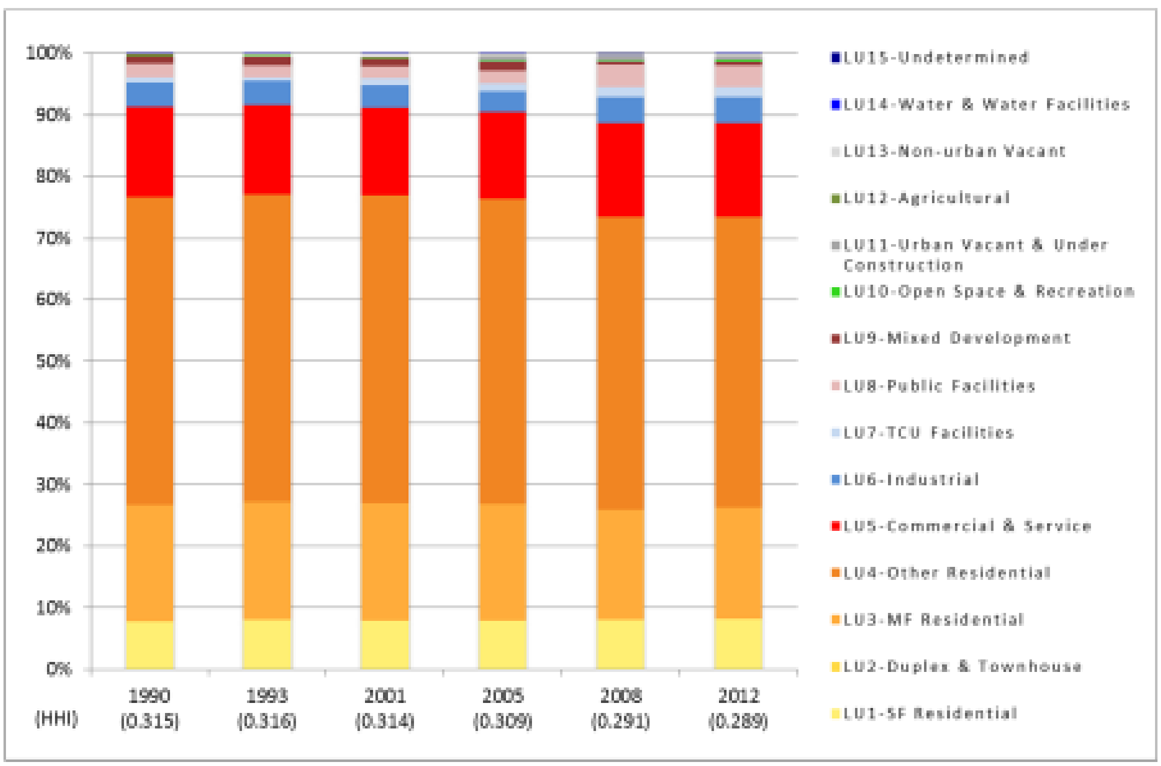

Figure 21f. Land use composition, 1990-2012 (TNI & Transit vicinity)

V. Land Use Change Analysis – Multinomial Logistic Regression Analysis

V-1. Model, Variables, and Data

While the previous explorative analysis reveals informative patterns of land use change in our study region, it does not enable us to distinguish the pure effects of transit on land use change dynamics from the influences of other factors. In this section, we present a more rigorous investigation designed to measure land use impacts of transit development/expansion. More specifically, we analyze parcel-level land use change by employing a multinomial logistic model, as shown below.[8]

$$\mathrm{P}\left(\mathrm{y}_{k|i} = j\right) = \frac{\exp(\beta_{ij} \cdot X_k)}{\sum_{m=1}^{M} \exp(\beta_{im} \cdot X_k)}$$

where β_{ij} indicates the estimated coefficients for each determinant (*X*, including transit variables) on the probability of land use conversion from *i* to *j*. Here, *M* represents all urban land use types considered in the model estimation. In our case, detailed land uses are classified into the following broad four categories: 1. Single-family Residential, 2. Multi-family Residential, 3. Commercial & Industrial (includes a wide range of non-residential urban activities including transportation, communication, utilities, public facilities, and mixed development), and 4. Open Space (includes conservation, parks, and recreational areas). Based on this categorization, we investigate the dynamics of i) new development (or infill development) of previously undeveloped land parcels (urban vacant, under construction, and non-urban vacant), and ii) redevelopment of industrial land from 2001 and 2012.

In our analysis, explicit attention is paid to each parcel's proximity to three types of rail transit stations. We identify land parcels near i) *Gold.First*: thirteen Gold Line Phase I stations; ii) *Before.GoldFirst*: stations opened before Gold Line Phase I; and iii) *After.GoldFirst*: stations opened after Gold Line Phase I; and analyze how the proximity to these stations influences new (infill) development or redevelopment dynamics in the study area. Furthermore, using the station-specific ridership count information obtained from Metro, we create an additional variable, *Low.Ridership*, indicating whether the parcel is located near stations (Gold Line Phase I only) with relatively lower ridership to explore the passible variation in the magnitude and significance of land use impacts.

Given that our analysis focuses on land use change between 2001 and 2012, *Gold.First* (representing parcels adjacent to the Gold Line Phase I stations opened in 2003) can enable us to

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[8] Multinomial logistic regression models have been increasingly employed in applied land use research. For more detailed description of this approach, please see e.g., McMillen (1989), Zhou and Kockelman (2008), Fragkias and Geoghegan (2010), and Kim et al. (2014).

capture the short-term land use impacts of transit development. In contrast, *Before.GoldFirst* can provide an opportunity to gain insights into the long-term (or indirect) effects, while the *After.GoldFirst* variable is expected to capture the influence that could emerge right after or even prior to transit station opening. It should be stressed that *Before.GoldFirst's* (long-term) effects are not solely attributable to the development of these stations that took place in the 1990s. Rather, these effects may be highly associated with the development of Gold Line Phase I, and subsequent expansion of the entire transit system may have contributed to improving the utility of old stations.

In addition to the transit variables, we consider other factors that could affect the probability of land use change to control for their potential influences. These control variables include:

- each parcel's physical conditions, including parcel size (*ln.Parcel.Size*, logged), shape (*Parcel.Shape*, the ratio of parcel area to square of parcel's perimeter), and slope (*Parcel.Slope*, calculated based on the national elevation dataset downloaded from the Multi Resolution Land Characteristics Consortium);
- neighborhood socio-economic characteristics (obtained from Census 2000 at the block-group level), such as the median household income (*ln.Nbhd.Med.Income*, logged) and the percentage of persons (25+ years old) who have a bachelor's degree or higher educational attainment (*Nbhd.Education*); and
- built environment and locational attributes, including population density (*Nbhd.Pop.Density*), road network density (*Nbhd.Road.Density*), the distance to Los Angeles' central business district (*Dist.CBD* and *Dist.CBD.Squared*), and the share of each category of land use in the neighborhood (*Nbhd.SF%*, *Nbhd.MF%*, *Nbhd.CI%*, and *Nbhd.OS%*).

The descriptive statistics of these variables, included in our new development and redevelopment model samples, are reported in Table 3. There were 182,173 vacant parcels and 51,893 industrial parcels (as of year 2001) in our new development and redevelopment datasets covering the entire Los Angeles County. In the table, the first five variables (i.e., No Transition; Transition to Single-family Residential; Transition to Multi-family Residential; Transition to Commercial & Industrial; and Transition to Open Space) describe whether the parcels remained in the same land use category or experienced a transition to another land use between 2001 and 2012. No Transition represents the baseline in our logistic regression. The means of No Transition for vacant and industrial parcels are 0.728 and 0.772, respectively, suggesting that approximately one-fourth of the land parcels in the study region underwent new- or re-development from 2001 to 2012.

Table 3. Descriptive statistics

Variables	Type	New Development Model Sample (Vacant Parcels)		Redevelopment Model Sample (Industrial Parcels)	
		Mean	SD	Mean	SD
No Transition	Binary	0.728	0.445	0.772	0.420
Transition to SF Residential	Binary	0.201	0.401	0.017	0.130
Transition to MF Residential	Binary	0.016	0.125	0.012	0.109
Transition to Com. & Industrial	Binary	0.032	0.176	0.149	0.357
Transition to Open Space	Binary	0.024	0.152	0.050	0.217
Gold.First.0.5 mile	Binary	0.003	0.051	0.008	0.091
Before.GoldFirst.0.5 mile	Binary	0.002	0.047	0.064	0.245
After.GoldFirst.0.5 mile	Binary	0.000	0.017	0.026	0.159
Low.Ridership.0.5 mile	Binary	0.002	0.046	0.001	0.037
Gold.First.0.75 mile	Binary	0.008	0.087	0.014	0.116
Before.GoldFirst.0.75 mile	Binary	0.005	0.071	0.120	0.325
After.GoldFirst.0.75 mile	Binary	0.000	0.020	0.032	0.176
Low.Ridership.0.75 mile	Binary	0.006	0.079	0.002	0.046
Gold.First.1 mile	Binary	0.012	0.108	0.022	0.147
Before.GoldFirst.1 mile	Binary	0.008	0.086	0.180	0.385
After.GoldFirst.1 mile	Binary	0.001	0.031	0.031	0.172
Low.Ridership.1 mile	Binary	0.009	0.092	0.004	0.061
ln.Parcel.Size	Continuous	8.411	1.832	7.381	1.354
Parcel.Shape	Continuous	0.206	0.049	0.195	0.051
Parcel.Slope	Continuous	12.107	15.359	1.298	3.453
ln.Nbhd.Med.Income	Continuous	10.904	0.493	10.489	0.503
Nbhd.Education	Continuous	0.176	0.142	0.127	0.116
Nbhd.Pop.Density	Continuous	508.2	1,032.7	2,128.4	2,369.9
Nbhd.Road.Density	Continuous	4.883	6.734	12.747	10.441
Dist.CBD	Continuous	56.088	22.510	20.276	12.907
Dist.CBD.Squared	Continuous	3,652.5	2,314.6	577.7	761.1
Nbhd.SF%	Continuous	0.135	0.212	0.139	0.194
Nbhd.MF%	Continuous	0.010	0.038	0.044	0.093
Nbhd.CI%	Continuous	0.101	0.143	0.266	0.194
Nbhd.OS%	Continuous	0.014	0.043	0.081	0.150
Under.Construction	Binary	0.070	0.255	NA	NA
Sample Size		182,173		51,893	

Note: The first five variables represent land use transition from 2001-2012.

V-2. Baseline Estimation Outcomes

Our baseline estimation results, in which a 0.5-mile radius is used to determine if each parcel is located within the vicinity of a transit station (as done in many previous studies – see e.g., Guerra et al., 2012), are presented in Tables 4 (new development model) and 5 (redevelopment model). According to the results from our new development model estimation, generally, transit investment is found to significantly facilitate development of previously undeveloped parcels, while there are some notable patterns of variation. More specifically, *Gold.First* (indicating parcels located within 0.5-mile of a Gold Line Phase I station), shows significant, positive effects on development probabilities for all four types of urban land use transitions, while the coefficients range from 1.215 (Commercial & Industrial) to 3.162 (Open Space). This result suggests that the provision of public transit service does facilitate new (infill) development in urban areas at least in short-run.

Parcels located near stations opened before Gold Line Phase I (i.e., *Before.GoldFirst*) are also found to be more likely to be developed, particularly for Single-family Residential and Commercial & Industrial purposes (0.377 and 0.289, respectively; significant at the 5% level), although the magnitudes of the estimated coefficients are smaller than those of *Gold.First*. This may imply that the positive impacts of transit can persist over a longer period of time (perhaps thanks to the continuing expansion of the transit system in the broader study area), while long-term effects may not be as large as immediate land use impacts of new station openings. In the case of parcels near stations opened after Gold Line Phase I (i.e., *After.GoldFirst*), new development for Multi-family Residential and Commercial & Industrial purposes seems to be facilitated. This finding may be associated with growing emphasis (and incentives) on more compact development in the process of recent transit development.

Our estimation results, however, suggest that such favorable effects would not be equally realized around every station. *Low.Ridership*, a dummy variable included in our analysis to explore if ridership matters, exhibits negative coefficients for all four types of new development. In particular, the deterrent impacts on Single-family Residential (-2.516) and Open Space (-3.023) are statistically significant at the 1% level. This finding deserves attention and further investigation with a more rigorous treatment of potential endogeneity, as it implies that public transit investment would not be able to generate expected land use outcomes, if the utility (or usage) of transit service is limited.

The estimated coefficients of the remaining explanatory variables meet our expectations. For instance, parcel slope is found to have significant, negative effects on development for urban purposes, except Open Space. In contrast, the median household income in the neighborhood shows a positive association with development probabilities, particularly for Single-family

Residential, suggesting that affluent areas are more likely to attract investment in new residential development. Population density also shows a similar, positive influence on new development of land parcels, as expected.

Another focus of this study is the effects of public transit development/expansion on revitalization of nearby areas. As explained above, we examine this by analyzing land use change (2001-2012) patterns of parcels which were initially used for industrial purposes using our multinomial logistic regression model. The estimation results are presented in Table 5.

In the case of redevelopment, *Gold.First* exhibits significant, positive impacts on the probabilities of redevelopment for Multi-family Residential (1.444) and Open Space (0.797). It should be noted, however, that the magnitude of the impact on Open Space is substantially smaller than that in our new development model presented earlier. This could be attributed to a large amount of costs involved in converting industrial parcels to Open Space in a short period of time. Also, *Gold.First* is found to have a moderate, negative association with the probability of redevelopment for Single-family Residential uses, indicating the difficulties in converting industrial sites to low-density residential purposes.

Before.GoldFirst's coefficients also suggest that the impacts of transit on redevelopment are not as strong as its influences on new development. The estimated coefficients for Single-family Residential turns out to be negative again, while these transit stations are found to facilitate the redevelopment of adjacent parcels for Open Space. *After.GoldFirst* even shows a negative association with the probability of redevelopment for Open Space, as well as Multi-family Residential. However, its impacts on the redevelopment for Commercial & Industrial turn out to be positive, consistent with its impact on new development for these land uses.

Table 4. Logistic regression results (New development model)

Variables	**(1) Single-family Residential**	**(2) Multi-family Residential**	**(3) Commercial & Industrial**	**(4) Open Space**
Intercept	-19.410 ***	-17.242 ***	-12.796 ***	-12.096 ***
Gold.First	1.964 ***	2.007 ***	1.215 ***	3.162 ***
Before.GoldFirst	0.377 **	0.120	0.289 **	-0.173
After.GoldFirst	0.401	2.120 ***	0.700 **	1.136
Low.Ridership	-2.516 ***	-35.191	-0.449	-3.023 ***
ln.Parcel.Size	-0.681 ***	-0.566 ***	0.211 ***	0.638 ***
Parcel.Shape	10.995 ***	8.457 ***	-0.472 *	-4.271 ***
Parcel.Slope	-0.029 ***	-0.062 ***	-0.059 ***	0.045 ***
ln.Nbhd.Med.Income	1.580 ***	0.984 ***	0.615 ***	0.130 *
Nbhd.Education	-1.563 ***	1.114 ***	0.230	-0.208
Nbhd.Pop.Density	0.00011 ***	0.00014 ***	0.00015 ***	0.00030 ***
Nbhd.Road.Density	0.025 ***	0.050 ***	0.010 ***	-0.038 ***
Dist.CBD	0.150 ***	0.322 ***	0.100 ***	0.054 ***
Dist.CBD.Squared	-0.00142 ***	-0.00416 ***	-0.00141 ***	-0.00069 ***
Nbhd.SF%	2.218 ***	0.328 **	1.116 ***	1.576 ***
Nbhd.MF%	0.252	1.413 ***	1.087 ***	1.006 *
Nbhd.CI%	1.215 ***	1.940 ***	3.200 ***	-0.486 **
Nbhd.OS%	3.226 ***	-0.776 *	3.083 ***	6.234 ***
Under.Construction	2.247 ***	2.011 ***	1.585 ***	0.654 ***

*** 1% level, ** 5% level, * 10% level significant; sample size = 182,173; pseudo r-squared: 0.358

Table 5. Logistic regression results (Redevelopment model)

Variables	(1) Single-family Residential	(2) Multi-family Residential	(3) Commercial & Industrial	(4) Open Space
Intercept	-5.300 ***	-7.801 ***	-1.116 ***	-5.683 ***
Gold.First	-1.700 *	1.444 ***	0.088	0.797 ***
Before.GoldFirst	-0.575 ***	0.192	-0.136 **	0.891 ***
After.GoldFirst	-14.693	-1.190 **	0.302 ***	-1.354 ***
Low.Ridership	-13.531	-15.731	0.150	-15.616
ln.Parcel.Size	-0.759 ***	-0.450 ***	0.088 ***	-0.377 ***
Parcel.Shape	8.462 ***	2.668 ***	-3.479 ***	-8.21 ***
Parcel.Slope	0.165 ***	-0.004	-0.039 ***	0.111 ***
ln.Nbhd.Med.Income	0.087	0.349 ***	-0.095 ***	0.398 ***
Nbhd.Education	-1.248 ***	3.081 ***	0.852 ***	-0.085
Nbhd.Pop.Density	-0.00018 ***	0.00006 **	-0.00004 ***	0.00004 **
Nbhd.Road.Density	0.046 ***	0.004	0.001	0.019 ***
Dist.CBD	0.149 ***	0.120 ***	-0.009 ***	0.145 ***
Dist.CBD.Squared	-0.00191 ***	-0.00155 ***	0.00017 ***	-0.00157 ***
Nbhd.SF%	2.331 ***	0.627 **	0.938 ***	-0.663 ***
Nbhd.MF%	2.966 ***	2.104 ***	2.694 ***	-0.257
Nbhd.CI%	2.781 ***	0.365	1.172 ***	0.499 ***
Nbhd.OS%	0.489	-0.548	-0.276 **	0.234

*** 1% level, ** 5% level, * 10% level significant; sample size: 51,893; pseudo r-squared: 0.094

V-3. Sensitivity Analysis

To check the robustness of our findings, we conducted the following two sets of additional analyses: i) model estimation with a small sample size obtained through propensity score matching; and ii) model estimation with the use of alternative transit vicinity boundaries (i.e., 0.75- and 1-mile radiuses). First, we employed a propensity score matching method[9] to identify one-to-one *matched* parcels, having characteristics similar to those located near transit stations (while maintaining our 0.5-mile radius to determine transit vicinity) and estimated our multinomial logistic regression model to see how the sample change can modify the estimation results. Second, we considered alternative ways to define transit vicinities using 0.75- and 1.0-mile radiuses and tested how the land use impacts differ when the expanded boundaries are taken into account. These estimation results are summarized in Tables 6 and 7.

Overall, our main findings from the baseline estimation are found to be quite robust, even though there are few notable exceptions. For instance, in most settings, *Gold.First* shows statistically significant, positive effects on new development for all of the four urban purposes considered, while the magnitude varies to some extent (Table 6). The only exception comes from the estimation with a small sample size obtained though the propensity score matching process. In this case, *Gold.First*'s land use impacts on new development tends to be smaller and relatively less significant than the baseline results. However, *Gold.First* still exhibits significant positive impacts on the probabilities of new development for Single-family Residential and Open Space at the 1% level. Furthermore, the deterrent effects of *Low.Ridership* are detected consistently, suggesting that the vibrancy of transit system can play an important role in inducing new (infill) development, particularly for Single-family Residential and Open Space.

Similarly, changes in our estimation setting do not appear to substantially modify our findings regarding transit's impacts on redevelopment of industrial parcels (Table 7). *Gold.First* is found to have positive impacts on the probabilities of redevelopment for Multi-family Residential and Open Space in all settings. Its negative impact on Single-family Residential is also detected in all cases, while the magnitude of the effect varies. The pattern of the coefficients on *Before.GoldFirst* and *After.GoldFirst* also remain largely unchanged, except in a few cases.

[9] The characteristics of near-transit parcels may have some systematic differences from those outside of the transit vicinities. To handle such differences and possible resultant biasedness, we employed a propensity score matching method to create a quasi-randomized experiment for non-randomized observations, which allowed us to compare outcomes of treatment and control groups in a more systemic manner (Rosenbaum and Rubin, 1983). More specifically, similar to Hurst and West (2014), we used a probit model to identify a control unit (i.e., matched land parcel) that had the closest estimated propensity score to the treatment unit (a parcel around a transit station).

Table 6. Sensitivity analysis results summary (New development)

Variables	Setting	(1) Single-family Residential	(2) Multi-family Residential	(3) Commercial & Industrial	(4) Open Space
Gold.First	baseline	1.964 ***	2.007 ***	1.215 ***	3.162 ***
	matching	1.795 ***	-0.024	0.522	3.338 ***
	0.75-mile	2.662 ***	2.535 ***	1.153 ***	2.747 ***
	1-mile	2.510 ***	2.550 ***	0.694 ***	2.127 ***
Before.GoldFirst	baseline	0.377 **	0.120	0.289 **	-0.173
	matching	0.117	-0.719 *	-0.135	-1.608 *
	0.75-mile	0.818 ***	-0.212	0.278 ***	-0.573
	1-mile	0.681 ***	-0.262	0.606 ***	-0.283
After.GoldFirst	baseline	0.401	2.120 ***	0.700 **	1.136
	matching	-0.567	-0.056	-0.360	0.747
	0.75-mile	0.160	1.408 *	0.707 **	2.422 ***
	1-mile	-0.999 *	0.652	-0.026	0.834 ***
Low.Ridership	baseline	-2.516 ***	-35.191	-0.449	-3.023 ***
	matching	-3.015 ***	-19.680	-0.142	-2.382 ***
	0.75-mile	-2.137 ***	-14.949	-0.533 *	-2.519 ***
	1-mile	-1.756 ***	-15.533	-0.235	-1.001 ***

Table 7. Sensitivity analysis results summary (Redevelopment)

Variables	Setting	(1) Single-family Residential	(2) Multi-family Residential	(3) Commercial & Industrial	(4) Open Space
Gold.First	baseline	-1.700 *	1.444 ***	0.088	0.797 ***
	matching	-2.234 **	1.137 **	0.195	1.096 ***
	0.75-mile	-1.325 *	1.001 ***	0.047	0.817 ***
	1-mile	-1.756 **	1.232 ***	0.122	0.570 **
Before.GoldFirst	baseline	-0.575 ***	0.192	-0.136 **	0.891 ***
	matching	-0.574 *	-0.010	-0.172 ***	0.572 ***
	0.75-mile	-0.445	0.236	-0.124 ***	1.008 ***
	1-mile	-0.087	0.296 **	-0.137 ***	0.915 ***
After.GoldFirst	baseline	-14.693	-1.190 **	0.302 ***	-1.354 ***
	matching	-15.288	-1.094 *	0.320 ***	-1.208 ***
	0.75-mile	-15.718	-1.406 **	0.269 ***	-1.766 ***
	1-mile	-15.618	-1.337 **	0.275 ***	-1.172 ***
Low.Ridership	baseline	-13.531	-15.731	0.150	-15.616
	matching	-12.699	-16.395	0.065	-16.517
	0.75-mile	-14.457	1.358 **	0.412 *	-1.457
	1-mile	-13.585	0.871	0.082	-0.382

In sum, our sensitivity analyses reinforce a couple of findings derived from the baseline model estimation. We confirmed *Gold.First*'s positive impacts on new development, suggesting that vacant parcels near Gold Line Phase I stations (opened in 2003) were more likely to be developed between 2001 and 2012 for various purposes. In other words, transit development or expansion in urban areas can facilitate land (infill) development in subsequent years. *Before.GoldFirst*'s coefficient pattern indicates the presence of long-term effects, although the magnitude tends to be smaller and significant only for Single-family Residential and Commercial & Industrial uses. As mentioned above, the persistence of these positive impacts could be associated with the continuing expansion of the public transit system in the study region. The opening of Gold Line Phase I and subsequent expansion might improve the utility of existing stations and thus promote further development in nearby areas.

The deterrent effects of *Low.Ridership* also deserve attention. *Low.Ridership* shows negative effects on new development, particularly for Single-family Residential and Open Space consistently. This finding may indicate that the presence of transit stations alone would not lead to infill development. Transit proximity appears to matter not only for new development but also for redevelopment of industrial sites. *Gold.First*'s estimated coefficients from our redevelopment model suggest that industrial sites are more likely to be developed for multi-family housing or open space if located close to newly developed transit stations. However, transit's contribution to overall redevelopment probabilities seem less evident than its contribution to new development.

VI. Summary & Discussion

This research empirically examines how transit investment shapes urban land use with a focus on the public (rail) transit system in Los Angeles County that has expanded over the last few decades. Using a historical geo-database of the changes in transit systems and land use, we attempt to identify key factors that shape and re-shape land use change patterns and measure the effects of transit development/expansion on parcel-level land use dynamics. This is mainly accomplished by conducting multinomial logistic regression analyses for new (infill) development and redevelopment of industrial sites, and the results seem to provide some meaningful lessons, as discussed below.

First of all, not surprisingly, our analysis results suggest that the near-transit parcels are more likely to experience development than those located outside of the vicinities of transit stations, consistent with the findings of previous studies that have reported substantial effects of transit investment on surrounding areas (Duncan, 2008; Pan and Zhang, 2008; Cervero and Kang, 2011; Grube-Cavers and Patterson, 2015). In particular, we detect significant, positive impacts of Gold

Line Phase I stations (opened in 2003) on the probabilities that vacant parcels will be developed for residential or commercial/industrial uses between 2001 and 2012. The large positive impacts may be associated with timely efforts/plans made by municipalities to facilitate more intensive land use in coordination with transit development, as discussed in Section 3.

Although relatively small in terms of magnitude, the presence of long-term effects is also found in our study, even after controlling for the influence of other factors, such as population density and other built environment characteristics. As mentioned in the previous section, the persisting positive impacts on the areas surrounding older rail transit stations (i.e., *Before.GoldFirst*) may not be solely due to the time lag between transit investment and land use change. In part, these effects would be generated by the continuing improvement and/or expansion of the entire transit system (through the development of Gold and Expo lines in our study area) that could significantly improve the utility of existing stations developed in the 1990s. These *indirect* benefits of transit expansion, largely ignored in most existing research, should not be underestimated in making transit investment decisions.

Another important thing to be stressed is the deterrent effects of stations with low ridership. Our multinomial regression results suggest that land use impacts of transit investment can be dampened significantly if the transit system is not vibrant enough. In other words, a cyclical relationship may exist between transit investment and land use change, and policy attention needs to be directed towards ways of realizing a virtuous circle (for instance, transit system vitality improvement – land development – further increase in ridership and efficiency).

According to our analysis, the way transit investment shapes redevelopment dynamics is not as evident as its impacts on new (infill) development. However, we detect significant positive effects of Gold Line Phase I stations on the probabilities of redevelopment of industrial lands for multi-family residential and urban open space uses, while industrial parcels were rarely converted to single-family housing. This finding may indicate the potential of transit investment as a facilitator of site reuse. Admittedly, successful site reuse (or brownfield redevelopment) often requires planning support and appropriate incentives, given the costs for environmental cleanup and/or uncertainties involved in the redevelopment process.

Questions arise whether land use changes triggered by transit investment fully meet our goals for creating more sustainable communities. Overall, our results suggest that transit development and expansion (through continuing investment) can contribute to inducing infill and redevelopment and thus achieving the vision of California's planning and SB375. However, there are some notable concerns. First, low-density (i.e., single-family) residential accounts for a large proportion of new development around transit stations in Los Angeles County. This pattern is particularly apparent in the areas with 0.5- to 1-mile distance from newly developed stations. More attention needs to be paid to these areas, which are often excluded from conventional transit-oriented planning processes with a narrow boundary of transit vicinity. Difficulties in promoting transit ridership and making all stations vibrant are another concern to be addressed. A systematic coordination of land use and transportation planning would be a solution, but little is known about how we can realize the virtuous circle effectively. Planners also need to pay attention to (potential) adverse consequences of rapid (re)development, especially the possibility of displacement and exclusion, in order to make sure transit investment leads to a more (environmentally and socially) sustainable future.

Achieving this vision of sustainability more successfully seems to require more concerted efforts of various players from civic activists to government officials. This research attempts to provide some meaningful insights into the connection between transit development and land use change and support more informed, collective decision making.

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