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Is Los Angeles Becoming Transit Oriented?

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Abstract

Over the past 20 years, local and regional governments in the Los Angeles metropolitan area have invested significant resources in building rail transit infrastructure that connects major employment centers. One goal of transit infrastructure is to catalyze the development of high density, mixed-use housing and commercial activity within walking distance of rail stations, referred to as Transit Oriented Development (TOD). This project examines the quantity, type, and mix of economic activity that has occurred around newly built rail stations in Los Angeles over the past 20 years. Specifically, have the number of jobs or housing market characteristics changed near stations? We use establishment-level data on employment and property-level data on housing transactions to analyze changes in several employment and housing outcomes. Results suggest that new rail stations were located in areas that, prior to station opening, had unusually high employment density and mostly multifamily rental housing. There is no evidence of changes in employment density, housing sales volume, or new housing development within five years after station opening. Regressions suggest that a subset of stations saw increased employment density within five to ten years after opening.

Keywords: Urban spatial structure, public transportation; economic development; housing
JEL codes: H4, O18, R1, R3, R4

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Section 1) Introduction

For most of the 20th century, Los Angeles was the quintessential car-oriented city. But over the past 20 years, local and regional governments have invested significant resources in building rail transit infrastructure that connects major employment centers, including downtown Los Angeles, Long Beach, Pasadena, and the eastern Wilshire Corridor. One goal of transit infrastructure is to catalyze the development of high density, mixed-use housing and commercial activity within walking distance of rail stations, referred to as Transit Oriented Development (TOD). By increasing the accessibility of station areas to other transit nodes, building new stations should increase surrounding land values, leading to higher intensity development. Prior research has found mixed evidence for whether rail stations impact transit ridership, property values, residential development, and employment. In this paper, we examine the quantity, type, and mixture of economic activity that has occurred around Los Angeles Metropolitan Transit Authority (MTA) rail stations from 1990 to 2010. The analysis examines whether station areas have experienced employment growth or changes in industrial mix of jobs, following station opening, and explores the time frame in which such changes may happen.

Standard urban economics models yield several hypotheses for how and why economic activity might change in areas where new rail stations are built. Following the standard monocentric city model, land values are highest at the central business district (CBD) and decline moving outwards, in proportion with increasing travel costs (Alonso 1964, Brueckner 1987, Mills 1967, Muth 1969). Localized improvements to transportation infrastructure that reduces travel costs – such as building a rail station that connects the station's neighborhood with an employment center (CBD or subcenter) -- will increase accessibility and decrease travel costs from that location and thereby increase land values, encouraging higher density development near the station (Anas 1995; Cohen and Paul 2007). Neighborhoods around rail stations should be relatively more attractive both to firms and households. Firms can potentially attract more consumers to convenient locations, particularly in industries such as retail, food service, entertainment and health care, and may offer lower wages to workers at that location. Households will be willing to pay higher rents/housing prices in exchange for lower transit costs. Therefore we would expect to see higher density of both residential and commercial development around rail stations. Whether and how much land values increase near stations should depend on the extent of improved accessibility to the location; for instance, stations that link to larger and denser rail networks should have greater impacts on land values. Rail lines that simply replace existing bus transit service have little impact on accessibility, and hence should not influence land values. Station effects will likely be highly localized, within one-quarter to one-half mile of the stations, because most passengers access rail stations by walking.

A fairly broad empirical literature has attempted to identify the impacts of rail transit investments on a variety of outcomes, including transit ridership, land values, housing prices, population and housing density, employment composition and population characteristics (see, for instance, Baum-Snow and Kahn 2005; Boarnet and Crane 1997; Bollinger and Ihlanfeldt 1997; Bowes and Ihlanfeldt 2001; Cervero and Landis 1997; Debrezion et al 2007; Handy et al 2005; Giuliano and Agarwal 2010; Kahn 2007; Kolko 2011; Lin 2002; Lund et al 2004; Mathur and Ferrell 2009; Schuetz 2015; Winston and Maheshri 2007). These studies have found mixed results of transit investment, depending on a number of factors; one crucial finding has been that the extent of changes in property values and related outcomes depends on the level of transit ridership, a market signal for the access provided by the investment. Low ridership produces few impacts. Another important factor is land use policy; cities may selectively zone to favor development around rail stations. The most relevant studies for the current analysis are Kolko (2011) and Schuetz (2015), which examine employment changes around stations for four large California MSAs, including Los Angeles. This project builds on these studies and goes into greater depth on the changes near Los Angeles transit stations.

Supporting the mixed findings of the academic research, casual observation of Los Angeles and other regions with relatively newer transit systems illustrates the variation in quantity and type of development near new rail stations. Stations along Metro's Red Line through Hollywood and the Gold Line in Pasadena have seen growth in apartments, stores, hotels and restaurants. Developers have already broken ground for projects along the planned extension to Santa Monica (Boehm 2014). However, little development has occurred along the Blue Line between Downtown Long Angeles and Long Beach (Allen 2010). This varied experience mirrors other parts of the country. For instance, portions of Arlington County, VA, adjacent to the Metro have more than doubled their commercial and residential square footage space in the past 20 years (Brosnan 2010). By contrast, the 30-year old commuter rail lines in suburban Boston still run through low-density residential areas with very little new development (Glaeser et al 2006).

The probability of TOD occurring depends both on market factors - does rail investment lead to increased property values - and on related policy decisions, notably land use regulation and other development incentives. Relevant market forces that affect the probability of TOD include proximity to existing employment centers, access to highways, the prior mix of economic activity, as well as demographic and economic characteristics of passengers and nearby residents. On the policy side, zoning has the potential to either constrain or enhance the probability of successful TOD. For instance, Arlington County engaged in coordinated zoning and planning efforts to encourage high-density mixed use corridors around the Metro, while preserving low-density single-family neighborhoods elsewhere in the county (Arlington County 2012). The Boston suburbs along the commuter rail lines prohibit commercial uses on the vast majority of their land and enforce very low densities for residential land (Glaeser et al 2006, Schuetz 2008). Analyzing the impact of transit stations on jobs and housing - specifically comparing the counterfactual of what would have happened in the neighborhood, in the absence of the station – requires an understanding of market and policy conditions prior to the beginning of rail service in the area. Notably, increasing the allowable density that can be built in a desirable location (known as upzoning) can increase land values even in the absence of transit infrastructure, because it increases the expected returns to development.

This analysis makes several contributions to the existing literature. First, relatively few studies have examined the impacts of rail transit on employment or commercial activity, although retail and services are key components of TOD. We measure the change in both employment and housing markets around stations, to develop a complete picture of economic activity in station areas. Second, we are able to conduct longitudinal analysis of treatment and control areas over a 20 year period, which allows us to test for pre-station anticipation effects and lagged changes. Third, because of the relative youth of LA' s system, impacts of transit in Los Angeles have been less studied than in many other cities, including San Francisco, Washington DC, and Atlanta. LA's history as a car-centered city makes this a particularly interesting empirical setting to determine whether introduction of a rail system has the capacity to change land use patterns. This research is particularly relevant in light of ongoing and proposed future rail investment in Southern California.

In this analysis, we combine data on the location and opening dates of rail stations along three rail lines in Los Angeles County with establishment-level employment data and property-level information on housing sales. We measure the level and industrial composition of employment and the volume and type of housing sales within one-quarter and one-half mile catchment areas of newly opened rail stations, before and after opening. As a comparison group, we identify a set of major road intersections more than one-half mile from any rail station, but within three miles of stations. We use a difference-in-differences approach to compare changes in employment and housing outcomes pre- and post-opening for station and control areas, as well as estimating annual changes for several time windows before and after station opening. Results indicate that the areas selected for new stations had unusually high employment density, prior to station opening. There is no evidence that employment near stations changed within a five-year window of station opening. Results do suggest that a small subset of stations, for which we observe the longest post-opening period, experienced increased employment within a five- to ten-year period after opening. It is unclear whether this reflects the time needed for land use patterns to adjust, or whether results are unique to the particular set of stations for which data are available. Analysis suggests that housing markets around station areas experienced no significant changes in sales volume, new housing development, or composition of sales after stations opened. A limitation of our analysis is that data are not available on changes in rental housing markets near stations, although many stations are located in predominately renter-occupied neighborhoods.

The remainder of this paper is organized as follows. Section 2 provides more context on Los Angeles' rail network. Section 3 discusses the data sources and empirical methods. Results of the analysis are presented in Section 4. Section 5 discusses policy implications and concludes.

Section 2) Background on Los Angeles rail network

Even after substantial investment in rail infrastructure, Los Angeles remains a car-oriented city. As of the late 2000s, 84 percent of the city's residents commuted to work by car, with fewer than seven percent using mass transit (Table 1). Even among transit riders, over 90 percent of commuters relied on buses rather than rail; these market shares have not changed appreciably since 1990 when the rail network began. Both the low overall transit share and the predominant reliance on buses make Los Angeles unusual when compared to large U.S. cities with older, more established rail networks. The relatively low usage of rail transit raises questions about whether proximity to rail stations is highly valued by residents, workers and firms, and thus whether station access will be capitalized into higher land values. The utility of a rail network is determined by how much it increases accessibility, that is, to what extent it facilitates passengers' ability to reach desirable locations. As shown in Figures 1 and 2, Metro stations are relatively thinly spread across a large geographic area; on average, each station is 1.25 miles from its nearest station (Schuetz 2015). The existing rail lines link several large employment centers to one another, but many residential areas, and a large share of the population, are too far from any rail station to make using the system practical for daily commuting.

One means of illustrating the demand for rail stations is the number of daily boardings (Table 2). Across all study-area stations, daily boardings averaged about 6,700 in 2013, the most recent year for which data are available. Boardings vary widely across stations and lines; the Purple and Red Line stations (mostly located in Downtown Los Angeles and along the Wilshire Corridor west of Downtown) draw the most riders, with over 13,500 average boardings per day, compared to about 1700 boardings at the Gold Line stations in Pasadena and the Arroyo Seco corridor north of Downtown. Looking at individual stations along each line suggests that connectivity to the broader network is correlated with ridership. The stations with the three highest number of daily boardings are Union Station (over 34,000), which serves the Gold, Purple and Red Lines, as well as the Metrolink commuter rail system and Amtrak; 7th St/Metro Center (27,000), serving the Blue, Purple, and Red Lines, and several major bus lines; and North Hollywood (17,000), the last station on the Red Line a first connection to the Orange Line bus rapid transit system serving the San Fernando Valley. The most used station on the Gold Line is Sierra Madre Villa (2,900), also the line's final station (prior to a planned expansion) and which, like North Hollywood, has a large adjacent park-and-ride lot. These stations likely attract riders from a larger area than the typical one-half mile catchment estimated for walking.[1] Stations with greater ridership are likely to be more attractive locations for firms and housing developers; unfortunately we do not have time-series ridership data by station and so cannot determine how much current ridership reflects changes that have taken place since station opening versus original population density or land use.

In an economically efficient world, in order to maximize the value of infrastructure, rail stations and lines should be located in areas with the greatest potential for ridership - based on the density of nearby population and jobs – and with potential for high-density development surrounding stations. In reality, the nearly three-decade-long planning for Metro routes was influenced by numerous competing political factions, including the Los Angeles Mayor and City Council members, Los Angeles County supervisors, members of Congress, city and county taxpayers, neighborhood residents, local business leaders, as well as civic, cultural, and

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[1] Commuters who reach rail stations by biking may also originate from a large catchment area, but we have no data on bike-to-train connections.

economic institutions throughout the region.[2] The general direction of each line as well as placement of some specific stations reflect compromises along multiple dimensions, not necessarily the same ones for each line. For instance, the Blue Line between Los Angeles and Long Beach was the first one built because of several advantages. Including Long Beach brought additional local tax revenues into the deal, and using existing rail rights of way reduced development costs. The route ran through the district of a highly influential Los Angeles County Supervisor, Kenneth Hahn, and through a largely industrial corridor with mostly low-income residents who generally supported transit, or at least were not organized in opposition to the route (Elkind, pp. 34-49). The Green Line was built down the middle of the 105 freeway as part of a consent decree resolving a lawsuit over the freeway's construction, involving nearby residents, multiple cities, Caltrans and the U.S. Department of Transportation (Elkind, pp. 63-70). The subway lines from Downtown Los Angeles to Hollywood and the San Fernando Valley were the most controversial route. Initially the subway was planned to run along Wilshire Boulevard from Downtown Los Angeles in the east to Fairfax Avenue on the west, one of the densest employment and housing corridors in the U.S. But political opposition from residents of several affluent Westside neighborhoods, and their representatives Congressman Henry Waxman and Los Angeles City Council member Zev Yaroslovsky, effectively forced the subway to turn north from Wilshire much farther east than originally planned (Elkind, pp. 79-100, Taylor et al 2009). The final route along Vermont Avenue was selected because it had fewer residential areas to raise opposition, and because the subway was supported by several large health and educational institutions along the route, such as Los Angeles City College (Elkind, p. 96).

[2] The lengthy and complex planning and development process is minutely documented in Elkind (2014). Taylor et al (2009) examine political influences for the Red Line. Here we briefly summarize a few of the general factors and examples that illustrate why rail station areas are systematically different than control areas.

Similarly, the stations in Hollywood were supported by the local Chamber of Commerce, which welcomed the potential revitalization impact on a declining area (Elkind, p. 118). In general, well-organized opposition by affluent homeowners blocked proposed routes that would have directly connected some of the largest and densest employment centers, resulting in routes through less dense, lower-end commercial and industrial corridors.

Besides the overall level of ridership, composition of Metro rail passengers may affect the potential for economic development near new stations. Holding constant the number of riders, higher income riders will have greater potential purchasing power and so increase the demand for housing and other goods and services near rail stations. According to Census data, the median household income of rail transit commuters living in Los Angeles and Pasadena is around $61,000, about $14,000 below incomes for car commuters and well above the $42,000 median income for bus riders. Many of the MTA's rail passengers had previously relied on buses as a primary means of transportation, prior to the opening of the rail system, so rail represents not an increase in total mass transit share but a switch across modes within transit (as evident in the flat overall transit share since 1990). In some instances, rail stations were built at locations with important bus connections (for instance, all the Purple Line stops along Wilshire Boulevard are served by the heavily used Metro Rapid 720 express bus). For such station areas, the site's accessibility through public transit may already have been capitalized into land values and development patterns prior to the rail station opening.[3]

Section 3) Data sources and empirical approach

We analyze changes in employment and housing market outcomes around 27 rail stations

[3] Unfortunately we do not have time-varying data on bus station locations and service lines.

that opened in Los Angeles County between 1992 and 2003. Outcomes include the number of jobs and industrial composition of employment, the number and structure type of houses built and sold, and housing prices. As a comparison group, we identify a set of intersections located more than one-half mile but within three miles of the rail stations. The analysis uses several variations on a difference-in-differences framework to test whether employment and housing changed near rail stations after station opening, relative to control areas. We test for both simple pre- and post-opening differences, as well as variation over time before and after opening.

3.1) Data sources

The location and opening dates of rail transit stations were assembled from the Los Angeles County Metropolitan Transportation Authority (Metro) website and supplemental documentation. The street address of stations has been geocoded and matched to latitude-longitude coordinates and census geographies. Information on which rail lines serve each station was also assembled. The research focuses on 28 stations along the Red, Gold, and Purple Lines of the Metro rail system, for which we have sufficient data on pre- and post-opening outcomes.[4]

Data on business establishments comes from the National Establishment Time Series (NETS) database, which contains the business name, geocoded address, NAICS industry code, and number of employees for all business establishments from 1992 to 2009. Using the NETS data, we calculate the number of establishments and employees within given geographic areas by industry category. The NETS data tracks establishments over time, so it is possible to determine the number of newly opened establishments as well as employment changes in existing

[4] The Blue Line stations opened in 1990, before our employment data are available, while the Expo Line and some Gold Line stations are too recent for us to observe post-station outcomes. The Green Line is excluded because most stations are located in the freeway median, making development immediately adjacent to the stations impossible. Descriptive statistics include all 28 stations, but regression analysis excludes the five stations that opened prior to 1996, because we do not observe at least three years of pre-opening employment.

establishments. Outcomes of interest are the total number of jobs near stations and the mix of jobs by industry category.

Housing market outcomes are created from property-level data on housing transactions from DataQuick, a private vendor that assembles and standardizes records from local government agencies such as tax assessors. We begin with all arms-length sales of residential properties in our study areas from 1988 to 2012, and apply filtering criteria to remove records with missing information on key variables (sales price and date, structure type, property size and age). Prices are adjusted for inflation to 2012 values using the CPI for all urban consumers, West region. We exclude properties with real prices below $1000 and above $5,000,000, on the grounds that extreme values may indicate non-arms-length transactions or highly idiosyncratic property characteristics which we cannot observe and control for. Key outcomes are the number of annual sales in study areas, the percent of sales that are single-family structures (an indicator of housing density), and real housing prices per square foot. We also estimate the number of new housing units added per year in the study areas, based on the "year built" indicator.[5] Several of the study areas have relatively few annual housing sales during the study period, because the building stock nearby is either non-residential or is composed mostly of large apartment buildings, which transact infrequently. For all analysis of housing prices at the study area-year level, we restrict the sample to study areas with at least 10 sales per area-year. The volume of sales also limits our ability to compare prices within specific property types (i.e.

[5] Estimating new housing units built from sales transaction data has some limitations, particularly for areas where much of the housing stock is renter-occupied or converted from non-residential uses. For instance, if a new apartment building is constructed on a lot that was previously vacant or non-residential, and the completed building is held by the developer after construction, then no sales transaction will be observable for the parcel and/or building. Similarly, conversion of existing non-residential buildings to residential use may not show up as new construction, if the "year built" variable is entered as the year of the original no-residential structure. Several of our study areas are located in mostly rental housing neighborhoods, and Downtown Los Angeles has added considerable housing units through adaptive reuse of non-residential buildings. Therefore our estimate of new housing development in these areas is a lower bound, and may substantially underestimate the true level of new construction.

single-family detached versus condominiums). Rather, we create a weighted average price per square foot across all property types, and in regressions control for the property composition of sales.

General economic and demographic characteristics on station and control areas is assembled from tract-level data from the 1990 and 2000 decennial census and the 2005-2009 American Community Survey. Treatment areas around stations are defined as circles with radius of either one-quarter or one-half mile, while control areas are similar sized circles around major intersections, described in more detail below. To match census tract characteristics to station and control areas, we use GIS to determine the percent of land in each study area drawn from each census tract, and created weighted averages of census variables using these percentages. Variables included in the analysis include population density and median household income.

3.2) Empirical approach

The research design compares changes in housing and employment outcomes near newly opened rail stations, before and after opening. As shown in Table 3, the stations along the rail lines studied – Gold, Purple and Red Lines -- offer sufficient variation in timing to allow analysis of housing and employment changes prior to and after development. The stations vary along a number of other dimensions that are likely to affect employment outcomes: some stations are below ground while others are above grade, and they are located in neighborhoods of varying economic, demographic, and physical characteristics. The density and mix of prior development around the station sites also varies: the Red and Purple Lines run through predominantly commercial parts of Los Angeles, as well as some residential areas near North Hollywood, while the Gold Line goes through both residential and commercial areas. About three-fourths of the stations are located within the city of Los Angeles, with six in the city of Pasadena and one in

South Pasadena. Treatment areas are defined as circles of either one-quarter or one-half mile radius from the rail station, which prior literature has shown is the typical catchment area for rail transit ridership (see Kolko 2010). We use one-quarter mile radius for Red and Purple Line stations, because these stations are located closely together and one-quarter mile gives mostly non-overlapping treatment areas. The Gold Line stations and Red Line stations in North Hollywood are located farther from one another, so we use one-half mile radius as the treatment area for those stations.[6]

The key challenge in determining whether new rail stations lead to changes in nearby economic activity is identifying plausible comparison areas: geographic areas that had similar characteristics to station areas prior to station opening and would have had similar trajectories over time but which were not affected by the new stations. As summarized in Section 2, historical evidence reveals that MTA station locations were selected based largely on political and fiscal compromises, which may not correspond to the most economically or geographically efficient sites. Nonetheless, it seems plausible that station locations differ from all non-station areas in Los Angeles County in ways that can affect subsequent development. Therefore we defined comparison areas based on several criteria designed to minimize pre-opening differences. First, comparison areas should be more than one-half mile from any rail station (new, existing or future), so will not directly be affected by the station. Second, they should be located within three miles of at least one newly opened station, so that they share general place-specific attributes, such as proximity to large employment centers or school districts. Third,

[6] The one-half mile treatment areas around three downtown Pasadena stations do overlap, but the half-mile catchment area was deemed more appropriate, given the presence of on-site station parking. The overlapping areas are in a sense doubly treated, which could introduce upward bias into the estimated impact of those stations. A few control areas have small overlaps with the station areas, which may bias results downward for those pairs, but the small number of overlapping control areas is unlikely to influence aggregate regression results.

because rail stations are almost always located at intersections of major streets, which will have relatively high volumes of car and pedestrian traffic, control areas are selected from among the intersections of similarly sized streets. In practice, we attempted to define control areas as intersections that shared one or more streets with rail stations (for instance, the intersection of Western Avenue and West 3rd Street is a comparison site for the rail station located directly south at Western Avenue and Wilshire Boulevard). Figures 1-2 show the location of the 28 station areas and 48 comparison areas in the study. The stations are widely distributed geographically, roughly forming a triangle between the North Hollywood Station (northwest corner) and Sierra Madre Villa Station in Pasadena (northeast corner, approximately 20 miles apart) and the 7th Street/Metro Center Station in Downtown Los Angeles (approximately 13 miles southeast of North Hollywood and 15 miles southwest of Sierra Madre Villa). Stations and control areas form several spatial clusters, so are assigned to five geographic submarkets: Arroyo Seco, Central LA, Downtown LA, North Hollywood and Pasadena (see Appendix Table 2).

We begin with a set of graphs and descriptive statistics, illustrating the levels and changes in employment and housing outcomes during the study period. We then use a modified difference-in-differences framework to compare station outcomes and comparison area outcomes, as illustrated in Equation 1.

$$(1) \qquad Y_{it} = \beta_0 + \beta_1 Station_i + \beta_2 Post_{it} + \beta_3 Post{*}Station_{it} + \beta_4 X_{it} + \varepsilon_{it}$$

In this equation, *i* indexes the study area, *t* indexes the year. *Y* is the employment or housing market outcome of interest, detailed below. *Station* is a dummy indicating station areas. *Post* is a dummy variable that is set to one after station opening (for comparison areas, this is based on the opening date of the nearest station). The coefficient of interest is β_3, on the interaction between *Station* and *Post*, indicating whether employment near station areas changes after station opening. X is a vector of control variables that could influence employment and housing outcomes in study areas and change over time, such as population density and household income. Models also include polynomial terms for year (year and year-squared), to control for larger economic time trends such as labor market conditions, and a set of fixed effects for the geographic submarkets described above.[7]

To get a broad understanding of economic activity around station and control areas, we look at several employment and housing outcomes. Employment measures include density (employees per acre) across all industry sectors as well as share of employment in each of four broad industry categories: commercial, industrial, public-institutional and miscellaneous (see Appendix Table 1 for NAICS 2-digit sectors assigned to the four industry categories). Housing metrics capture both the volume of activity (number of sales and newly built units per 100 acres), the structure types of properties sold, and real prices per square foot.

The pre- and post-opening framework may obscure an important question: do employment or housing patterns vary differently across years, either before or after station opening? There are several plausible hypotheses about how outcomes might vary over time that would not be captured by a simple before-and-after analysis. As discussed in Section 2, station planning and development occurred over many years, with chosen locations announced well before construction and operation commenced. Therefore land use patterns, physical development and employment patterns could change prior to station opening, in anticipation of rising land values. Alternatively, employers or real estate developers may be reluctant to expand employment or construct buildings near a planned station until a few years after operation, to

[7] We include time trends as polynomial terms rather than a set of year fixed effects to avoid collinearity with years of station opening. Robustness checks using linear year and higher order polynomials suggest a squared term is the appropriate functional form.

observe the volume of transit riders and effectiveness of the new rail line, in which case there may be a substantial delay before aggregate economic patterns change. In car-oriented cities like, Los Angeles demand for rail transit will be particularly uncertain. To test for varying employment and housing patterns over time, we estimate the following regressions, shown in Equation 2:

$$(2) \qquad Y_{it} = \beta_0 + \beta_1 Station_i + \beta_2 YrsPre_{it} + \beta_3 Station{*}YrsPre_{it} + \beta_4 YrsPost_{it} + \beta_5 Station{*}YrsPost_{it} + \beta_6 X_{it} + \varepsilon_{it}$$

In this equation, *YrsPre* is a continuous numeric variable indicating the number of years prior to station opening (equal to zero for all years after opening), *YrsPost* is the count of years after station opening (equal to zero for all years prior). The interaction term, *Station*YrsPost*, gives the coefficient of interest, indicating the difference in employment and housing associated with each year post-opening for station areas, relative to control areas. Regressions include the same control variables, year polynomial terms and fixed effects for geographic submarkets. [8]

3.3 Additional challenges to identification

The regression analysis implicitly tests the hypothesis that increases in land values due to station areas' improved accessibility will result in higher density, or higher value, economic activity. However, localized public policy interventions, particularly land use regulation, have the potential either to enhance or constrain market pressures on economic outcomes near stations. For instance, if new stations are opened in areas zoned for low-density, exclusively residential land use, then it is unlikely that large volumes of new housing or employment could emerge near the station, even if firms and developers wished to locate nearby. Alternatively, if

[8] As a robustness check, we also estimate regressions with a full set of dummy variables for each year pre- and post-opening, summarized in Appendix Table 4. Results of the fully interacted model are substantively similar to the simpler interactions with continuous number of years.

zoning grants developers density bonuses or other incentives to locate near stations, relative to equivalent sites not near transit, then the regulation could result in more economic activity near the station than markets alone would have provided. Prior research has shown that land use regulations in a variety of forms can exert substantial effects on the quantity and price of housing (Glaeser et al 2005, Quigley and Raphael 2004, Schuetz 2009). Unfortunately, developing accurate quantitative measures of zoning at small geographic areas is extremely difficult, due to scarcity of data and the complexity of modern land use regulations (Glaeser et al 2006, Gyourko et al 2008). Below we discuss two zoning changes that may affect housing market outcomes near some rail stations, and their potential influence on our results. In the conclusion, we describe some specific examples of how zoning and other public interventions near three of our station areas, based on qualitative case studies (Schuetz et al 2015). In general, because zoning and other public interventions may either constrain or enhance development, it seems likely not directly controlling for local policies will introduce measurement error but will not consistently bias our results.

One policy intervention that occurred during our study period may have affected housing market near station and control areas in Downtown Los Angeles. In 1999, the Los Angeles City Council enacted an Adaptive Reuse Ordinance to encourage conversion of vacant commercial buildings into housing, through an expedited approval process and waivers of some zoning and code requirements that apply to new construction.[9] The ordinance initially applied only to Downtown Los Angeles, but in 2003 was expanded to other parts of the city. The Department of City Planning estimates that the Adaptive Reuse Ordinance has been a substantial and direct stimulus to the Downtown housing market, resulting in the creation of several thousand housing

[9] http://preservation.lacity.org/incentives/adaptive-reuse-ordinance

units since 1999. In terms of our analysis, the ordinance should have similar impacts on both stations and control areas within parts of the city where it applies, as long as the composition of building stock is similar (i.e. presence of vacant commercial buildings eligible for conversion). But the chronological proximity of another spatially-based policy makes it more difficult to disentangle the effects of rail stations from those of the ordinance in affected neighborhoods.

Another potentially confounding factor is the state density bonus program, amended by Senate Bill 1818 in 2005. Under this program, the City of Los Angeles grants developers a 35 percent density bonus (based on housing unit counts) for new housing projects constructed within 1500 feet (0.28 miles) of a mass transit stop that set aside at least 15 percent of units for very low and low income households (Los Angeles Department of City Planning 2005). The density bonus may result in developers relocating potential projects closer to transit stations; our analysis cannot distinguish the effects of the rail station itself on land values from that of the density bonus.[10] The transit-oriented density bonus could bias our results upwards for stations in the City of Los Angeles, overestimating the true effect of station openings on nearby housing development. However, the state density bonus only applied in the latter years of our study period, so it is likely that few qualifying projects could have been completed during this time.

Section 4) Results

The locations in which new rail stations were built during the 1990s and 2000s had unusually high employment densities and predominantly multifamily rental housing, prior to station opening. Employment densities and housing market outcomes in station and control areas fluctuated somewhat over time with macroeconomic cycles, but there is no clear time trend

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[10] Boarnet (1998) finds that street and highway infrastructure improvements relocate productivity gains towards areas with better infrastructure, rather than creating net gains.

in employment or sales volume among study areas. Housing prices increased over time in both station and control areas, with no significant differences around stations. Descriptive statistics and regressions both indicate that station areas did not see employment growth or increased housing sales volume within the first five years after station opening. Regression results suggest that a small group of stations that opened between 1996 and 1999 saw significant employment gains between five and ten years after stations opened.

4.1 Descriptive statistics: Employment and housing metrics

A substantial difference between the rail system in Los Angeles and those in older cities such as New York and Boston is that land use and employment patterns were well established before LA's rail stations were built. As noted in Section 2, rail lines were intended to connect existing employment centers, enhancing access of potential workers to job-rich areas. An analysis of pre-opening station area characteristics confirms that areas where rail stations opened during the 1990s and 2000s already had high employment densities well before the rail network was built (Table 4). The average station area had nearly 70 employees per acre as of 1992, four times the employment density in control areas. Both station and control areas had much higher employment density than Los Angeles County overall, suggesting that the selected control areas form a better counterfactual to station areas that the remainder of the county. Establishments near future stations were, on average, nearly 50 percent larger than establishments in control areas, measured by employees per establishment. Station and control areas share two prominent employment sectors: retail (44-45) and health care and social assistance (62) each make up 10-12 percent of employment. Beyond those sectors, employment near stations was more weighted towards commercial sectors, including professional, scientific and technical services and accommodation/food services, which are typical users of retail and office buildings. Control areas leaned more towards industrial sectors, mostly wholesale trade and manufacturing, which tend to be located in buildings with lower floor-to-area ratios.

Comparing the number and type of housing sales near station and controls areas also suggests some differences in the underlying housing stock. Station areas had roughly half as many housing sales per year in 1990, but twice as many newly built housing units, implying that the housing stock in station areas is more heavily weighted towards multi-unit structures. Looking explicitly at the composition of housing sales by structure type confirms this: 30 percent of sales near stations were for single-family homes, compared with 56 percent of sales in control areas. Condo sales represented more than one quarter of sales near stations, with the remaining 44 percent in multifamily buildings (mostly small, 4-8 unit buildings). Although the sales data only reflect housing units that change ownership, it seems reasonable to extrapolate that the overall housing stock in station areas is more weighted towards multifamily buildings, either condominium or rental. Despite the differences in structure type and sales volume, the median sales price per square foot was similar in station and control areas, just over $250 as of 1990 (in constant 2012 dollars).

Station and control areas differed somewhat in population characteristics, prior to development of the rail network, but these differences are less pronounced than the pre-station differences in employment or housing patterns. Both station and control areas had higher population densities than Los Angeles County overall. As of 1990 residents near station areas had lower incomes than the population in control areas and the county overall. The populations in both station and control areas tended to be slightly more Hispanic and Asian than Los Angeles County, with slightly lower African-American population shares.

The implications of these differences for future job and housing growth are not immediately obvious. It is possible that the more industrially oriented control areas will be less desirable for additional development, or may not be zoned for mainstream commercial uses. Alternatively, areas with more industrial uses might offer more large-scale land parcels for redevelopment, or face less opposition from existing landowners and tenants at the prospect of new, higher-density development. The higher prevalence of single-family housing in control areas may imply more restrictive zoning that would constrain higher-density residential or commercial development. Lower incomes in station areas may suggest that those areas were initially less attractive sites for new development. Thus it is unclear whether and in what direction pre-existing differences might bias regression results.

Figures 3 and 4 show average employment density and housing sales volume, respectively, near station and control areas over time, indicating years in which groups of stations opened. Because stations opened intermittently over a relatively long period that includes several business cycles, we try to distinguish the effect of the stations from changes in general economic conditions. Average employment densities in both station and control areas show some cyclical movements between 1992 and 2009, decreasing during the recessions of the early 1990s, just after 2000 and the Great Recession from 2007 to 2009 (Figure 3). These cyclical variations generally match time trends in employment density for Los Angeles County as a whole. However there is no clearly apparent time trend (up or down) among the study areas, nor does visual examination of the graph show clear evidence of employment changes around station opening dates. Housing sales volume in both station and control areas fell substantially from 1988 to 1992, reflecting the recession of the early 1990s (Figure 4). While sales volume in control areas recovered during the housing boom of the late 1990s and early 2000s, sales volume near station areas remained well below the 1988 levels throughout most of the study period. This may reflect compositional differences between station and control areas: the multifamily housing market nationwide weakened after the 1986 Tax Reform Act substantially reduced income tax benefits to holding real estate investments. Sales in both station and control areas fell sharply during the housing bust (2007-2009), then recovered somewhat in control areas. The graphs do not suggest noticeable changes in sales volume around the years in which stations opened.

To focus more clearly on the time periods of interest, Figures 5 and 6 show average annual employment and housing sales density, beginning three years before station opening and ending five years after station opening. The employment analysis includes only the 23 stations and matched control areas for which at least three years of pre-opening employment data are available.[11] Housing sales data extends back to 1988, so the housing analysis excludes only one station (7th/Metro Center) and two control areas. The year of opening is defined for each station/control area, so that t_0 represents different years for each cluster of stations/controls. Average employment densities are virtually flat during the pre-station years and for one year afterwards for both stations and control areas (Figure 5). Station areas show a modest increase between years two and five, from about 32 employees per acre to about 34 employees per acre. Control areas have flat employment density through year three after station opening, then an increase of just under one employee per acre from years three through five. Housing sales density is lower in all years in station areas, between about 8 and 10 sales per 100 acres, compared to between 12 and 16 sales per 100 acres in control areas (Figure 6). Sales volume

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[11] Dropping the three earliest Red and Purple Line stations reduces the average employment density among stations by roughly one half, from about 60 employees/acre to about 30, because the earliest stations include the highest density employment centers in Downtown Los Angeles.

fluctuates somewhat over time, but follows essentially the same time patterns in station and control areas. The graphical analysis does not attempt to determine whether these small changes are statistically different from zero.

Before estimating regressions, we compare our main outcome variables for both employment and housing for the three years before and after station opening. For the employment analysis, we calculate average employment density and share of employment in each of the four industry categories for station and control areas over three years, pre- and post-opening (Table 5). Using a three-year window allows for the possibility that employment patterns might begin changing prior to opening due to anticipation, or that it changes might take several years after opening to become evident.[12] None of the five employment outcome variables show significant changes from the three years prior to station opening to the three years after opening, either in station or control areas. Among station areas, there are small increases in employment density, commercial employment share and public/institutional employment share, but none of these differences are statistically different from zero or substantively large in magnitude. The largest change is a nearly three percentage point decrease in industrial employment share, but this is also not significant at the 10 percent level or higher. Among control areas, overall employment density is essentially the same before and after opening years of the matched station areas. Commercial and public/institutional employment shares increased slightly, while industrial and miscellaneous employment shares decreased slightly, with no differences attaining statistical significance. The difference in means tests are consistent with

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[12] We have examined annual data for these intervals separately for each station and for groups of stations that open in the same year, because the impact of opening might vary across points in the economic cycle. There are not observable time trends within the three-year windows, nor apparent variation in time trends across stations (see Appendix Table 3). The annual data is reasonably smooth, not displaying large year-over-year variations that would raise concerns about short-term noise-to-signal ratios. Therefore the remaining analysis will use annual employment metrics, to allow for clean identification of before-and-after periods.

Figures 3 and 5, which show substantially higher levels of employment around stations than in control areas, but do not indicate noticeable changes in employment levels immediately after station opening for either set of study areas.

Parallel analysis of several housing outcome measures also reveal few significant changes in housing markets, pre- and post-station opening (Table 6). The outcome variables include the density of housing sales, the density of new housing units built, share of housing sales composed of single-family structures and condominiums, and the median price per square foot. After station opening, station areas show slightly higher volume of sales and new housing development, a higher share of condominium sales and lower share of single-family sales – all consistent with increasing housing density after stations opened. However, none of these differences are statistically significant. All these changes are also exhibited in control areas, with only one marginally significant difference (sales volume). The one housing outcome that does change significantly after station opening is price per square foot, which increases by a meaningful and significant amount in both station and control areas, with station areas showing a larger absolute and percentage increase in prices.

4.2 Regression results: Employment and housing changes

As a more rigorous test of whether employment around stations changed after stations opened, we estimate a series of regressions summarized in Table 7. We begin by estimating pre- and post-opening differences in the three-year window around station opening, then gradually expand the time period to five years before and after, ten years after, then using the entire set of years available in the dataset. Stations that opened prior to 1996 are excluded from the regression analysis, because we do not observe pre-opening employment.[13] This approach provides some insight into when any impact of stations on employment levels might become apparent, given that there could in theory either be anticipatory pre-opening changes or delayed impacts. We estimate changes first through use of simple indicators for pre- and post-opening, then measuring number of years pre- and post-opening as a continuous variable.

Regression results suggest that there is no immediate impact of station openings on nearby employment levels, but that employment may increase in the five- to ten-year window after stations open. All models confirm a key result from prior graphs and descriptive statistics, that rail stations were situated in areas with much higher initial employment density than the nearby intersections that were not chosen as sites for rail stations. Beginning with the narrowest time window, three years before and after opening, the coefficient on *Post*station* is small, negative, and not statistically different from zero (Column 1). Expanding the window to five years before and after opening, the coefficient on *Post*Station* becomes positive but is still small and insignificant (Column 2). The magnitude on *Post*Station* increases again when the time frame is widened to ten years after station opening and is closer to attaining statistical significance, although still short of the 10 percent level (Column 3). We can only observe ten years of post-opening employment for eight stations, up to nine years of post-opening employment for another three stations, while we observe at most six years of post-opening employment for the 12 Gold Line stations. Finally expanding the analysis to include all years, the coefficient on *Post*Station* triples in magnitude from the previous model and is now significant at the five percent level (Column 4). This suggests that the employment gains

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[13] Estimating the regressions for variations on these time windows, include three years prior to opening to five or ten years after opening, yields very similar results. Including stations that opened prior to 1996 does not alter the estimated coefficients but is conceptually less clean.

discerned in the regression occur for the stations that opened around 1996-99, and became evident towards the latter part of the study period. Because that period coincides with the Great Recession, it may in fact be that those station areas lost less employment during the downturn than control areas, rather than experienced absolute employment gains.

To further examine the time trends in employment, we estimate a parallel set of regressions using continuous counts of years pre- and post-station opening (Table 7, Columns 5-8). Results are very similar to those using a binary indicator for post-opening: the coefficient on *Station*YrsPost* does not become positive and significant until the study window includes up to ten years post-opening (Column 7), and increases in both magnitude and significance when using the full set of years (Column 8). Qualitative analysis of one station, the Hollywood and Vine stop on the Red Line, illustrates why development may not appear for several years. The Los Angeles Community Redevelopment Agency (CRA) used eminent domain to help assemble parcels near the station, enabling the MTA to undertake a large-scale redevelopment of the station area, complete with high-density multifamily housing, a hotel, and substantial ground-floor retail space. Even with concerted efforts by the city, the MTA and a private developer, the redevelopment project was in progress from 2001 to 2009, only reaching completion ten years after the station opened. The Hollywood and Vine case is atypical in the level of public involvement, but raises questions about how quickly redevelopment may become apparent in aggregate data. We only observe a sufficiently long post-opening period for a limited set of stations that opened between 1996 and 1999, and so cannot infer whether the apparently long lag reflects true redevelopment times or some unobserved characteristics for the particular group of stations.

While employment levels may adjust slowly because of the time needed to construct or reconfigure buildings, the composition of employment across industries could adjust more rapidly using existing space. Therefore we estimate a set of regressions on the employment shares across four industry categories, over five- and ten-year windows post-station opening (Table 8). The coefficients from the five-year window before and after opening (Columns 1-4) show similar results to the difference-in-means tests shown in Table 6. During the immediate five-year period after station opening, employment in station areas shifted towards commercial and public/institutional jobs, away from industrial and miscellaneous sectors, although the changes are not significantly different from control areas. Over the longer time period, up to 10 years after station opening, there were significant gains in public/institutional employment shares relative to control areas, at the expense of employment in the other three industry categories (although none of the negative coefficients are statistically significant). One possible explanation for this shift in overall employment composition is that public sector organizations located near stations, including medical facilities and schools, had relatively smaller employment losses during the Great Recession than private sector firms.

Next we examine changes in employment density post-station opening for each of the four geographic submarkets with clusters of stations that opened in 1996 and later (Table 9).[14] The regressions coefficients indicate that in three of the four submarkets – Central LA, North Hollywood and Pasadena - stations were sited in initially more employment-rich locations than control areas not selected for stations. However, there is no statistically significant evidence that employment near stations increased after opening across any of the submarkets. All the stations in the Arroyo Seco and Pasadena clusters opened in 2003, so if employment does not

[14] Only one station in Downtown Los Angeles, the Chinatown station, opened after 1996, so we omit the DTLA cluster from these regressions.

significantly increase until five or more years after opening, it may be too early to detect any gains in these areas. However, there is also no evidence of employment growth around the Central Los Angeles and North Hollywood stations that have been operating since 1996-1999, when estimating regressions for these groups of stations separately.

The results for similar regressions on housing market outcomes confirm some of the pre-opening differences between station and control areas, but provide little evidence that housing markets changed around station areas, after rail service began. We estimate similar forms of regressions to the baseline employment models in Table 8, using the continuous measures of years pre- and post-opening, and focusing on two time windows: five years before and after station opening, and up to 10 years after opening (Table 10).[15] The first two columns examine changes in sales volume; station areas had lower housing sales volume than control areas, but the gap does not significantly change over time, and indeed coefficients on *Station*YrsPost* are close to zero. These results match the graph in Figure 4 and difference in means estimates in Table 6. Looking at volume of new housing development reveals almost no statistically significant differences between station and control areas, pre- or post-opening (Columns 3-4). However, analyzing new development using housing sales data may underestimate the true amount of new housing by omitting rental properties.[16] Columns 5 and 6 provide additional evidence that housing sales in station areas are less weighted to single-family properties across all years, but do not indicate significant changes in the composition of sales over time, for either station or control areas. The only housing outcome to show significant changes in station areas after station opening is housing prices per square foot, and here the sign is the opposite of that predicted: for

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[15] Robustness checks using the post*station dummy and for all time windows produce nearly identical results.
[16] Qualitative case studies of selected stations find that both the Hollywood and Vine station on the Red Line and the Del Mar station on the Gold line have had new apartment developments during our study period, but because the buildings have not been sold, they do not appear in the DataQuick transaction data (Schuetz et al 2015).

each of the five years after stations opened, prices near stations increased by less than prices in control areas (Column 7). The sign on *Station*YrsPost* is still negative for the 10-year window after opening, although smaller magnitude and not significant (Column 8). Although these results appear to contrast with the difference in means estimates in Table 4, it should be noted that the regressions include measures for year and year-squared, essentially controlling for time trends across all study areas, and that the coefficient on *Year post* is also negative for control areas. Thus the interpretation of *Station*YrsPost* is that, controlling for observable neighborhood characteristics and general macroeconomic trends, prices in station areas grew by less than in control areas, after stations opened. All results on prices should be interpreted with the further caveat that the sample is restricted to study areas with at least 10 sales, and that several of the more centrally located stations and control areas drop out of the regressions.

In sum, the regression results provide limited evidence that some stations experienced employment gains more than five years after opening, while housing markets around station areas do not appear to have changed significantly in the years after rail service began.

Section 5) Conclusions and policy implications

The Los Angeles metropolitan area is one of several regions in the U.S. that has recently made substantial public investments in building subway or light rail stations. Developing new transit infrastructure can have multiple goals, including increasing access to existing job centers or public facilities, encouraging high density housing near transit and retail, reducing the growth of vehicle traffic and road congestion, and spurring physical and economic development. A broad academic literature has studied the impacts of transit infrastructure on various economic outcomes, with widely varying findings across cities. Because Los Angeles' rail transit system is still quite new, little analysis has been conducted on its impacts. In this paper, we add to the literature on transit oriented development by examining whether and how employment and housing patterns have changed around newly opened rail stations in Los Angeles during the last two decades.

Results of the analysis reveal that the locations in which new rail stations were built during the 1990s and 2000s had unusually high employment densities and more multifamily housing, prior to station opening. Employment densities and housing sales volume in station and control areas fluctuated somewhat over time, with macroeconomic cycles, but there are few clear time trends among study areas. Descriptive statistics and regressions both indicate that station areas did not see employment growth within the first five years after station opening. Regression results suggest that a small group of stations that opened between 1996 and 1999 saw significant employment gains between five and ten years after stations opened. Analysis suggests that housing markets around station areas experienced no significant changes in sales volume, new housing development, or composition of sales after stations opened. For those stations with sufficient sales volume to analyze price changes, housing prices near stations increased by less than in control areas, after stations opened. A substantial limitation of our analysis is our inability to observe changes in rental housing markets, such as rent levels or the number of new rental units built.

Another limitation is that we cannot control for zoning or other localized policy interventions that may affect development around stations. However, qualitative case studies of a few stations reveal several different ways in which zoning or pre-existing land use patterns could matter. Station areas vary in the baseline zoning that determines what type and density of land uses are permitted by right; high-density residential and commercial uses consistent with

TOD are allowed near all three stations in Downtown Pasadena and some parts of Central Los Angeles, but at least one station (Civic Center) is zoned to allow only public facilities and government buildings. The City of Pasadena adopted new, density-friendly zoning around all its downtown station areas around the time that Gold Line service began. By contrast, the City of Los Angeles has at best allowed piecemeal rezoning or variances around selected stations, and those changes were not necessarily implemented at the time of station opening. Moreover, many of the stations are located in densely developed areas with highly fragmented land ownership, so that large-scale redevelopment will require complex and costly land assembly, which adds to the uncertainty and time needed for development. The example of the Hollywood and Vine station also suggests that, even in areas with strong market demand and density-friendly zoning, it may take several years for changes to land use patterns and physical development to emerge.

Given the apparently limited change in jobs or housing near average Los Angeles rail station, should the public investment in building these stations be considered successful? One possible response is that encouraging new development/job growth is only a secondary goal of mass transit systems, and the more important measure of success is whether rail stations increase access to existing employment centers or other amenities (either by creating new linkages or by improving the reliability or quality of prior transit modes). Despite the complicated political considerations that drove the route planning – or perhaps because of the need to avoid established residential neighbors who opposed rail - Los Angeles's rail stations were located in areas with high initial job and housing density, although the system does not create direct connections to important job centers on the city's west side. Additionally, Los Angeles' transit system is still quite new, relative to the legacy systems in New York and Boston, or even systems like Washington's Metro and San Francisco's BART, that date back to the 1970s. Both the qualitative and quantitative results suggest that new development patterns may take years, even decades, to emerge around the stations. The varying approaches taken by local governments in Pasadena and Los Angeles to zoning around the stations does suggest that local governments that wish to encourage transit oriented development should consider a more integrated approach to transit investment and land use planning. The involvement of Los Angeles' CRA in the Hollywood and Vine neighborhood illustrates another potential role for local government, as development facilitator and coordinator. Since our study period, the MTA has begun a TOD Planning Grant program to help local governments revise their land use regulations around stations in ways that can accommodate and encourage development. Since its adoption in 2011, the TOD Planning Grant Program has funding roughly 35 projects over four rounds of funding.[17] This offers one alternative way to coordinate land use planning and infrastructure development across multiple agencies within the region; evaluating its effectiveness will be an interesting area for future research.

[17] https://www.metro.net/projects/tod/

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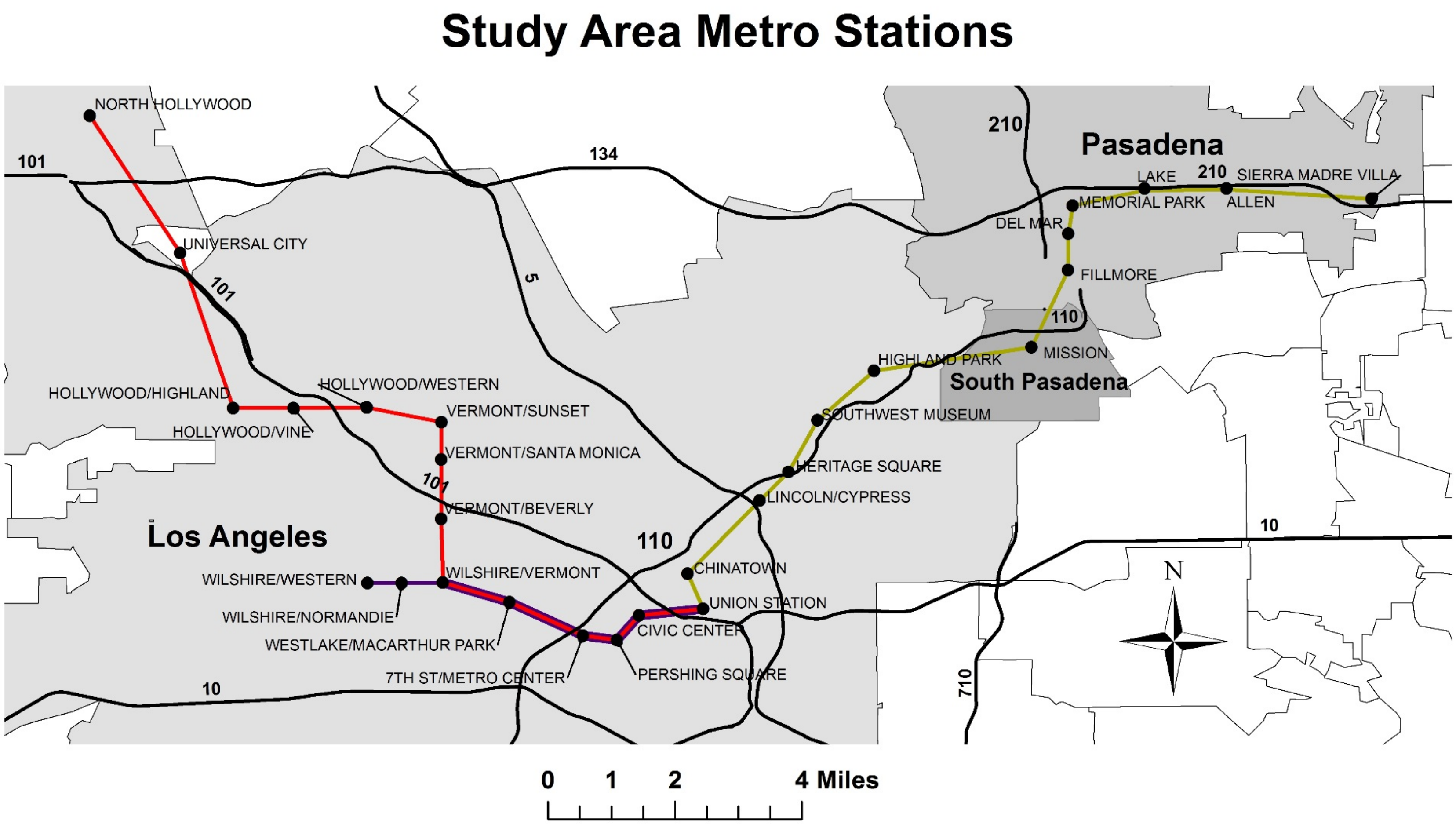
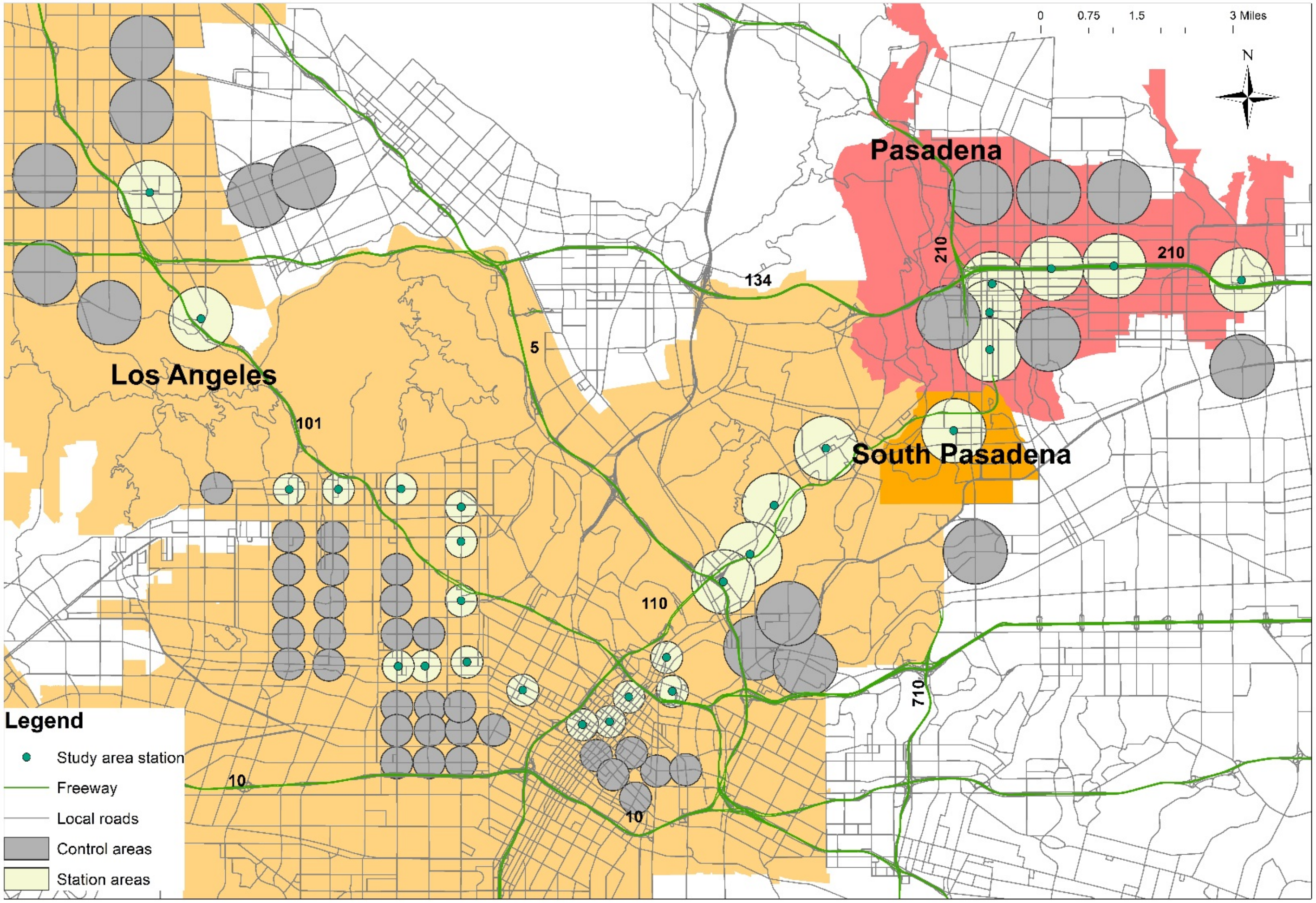
Figure 1:



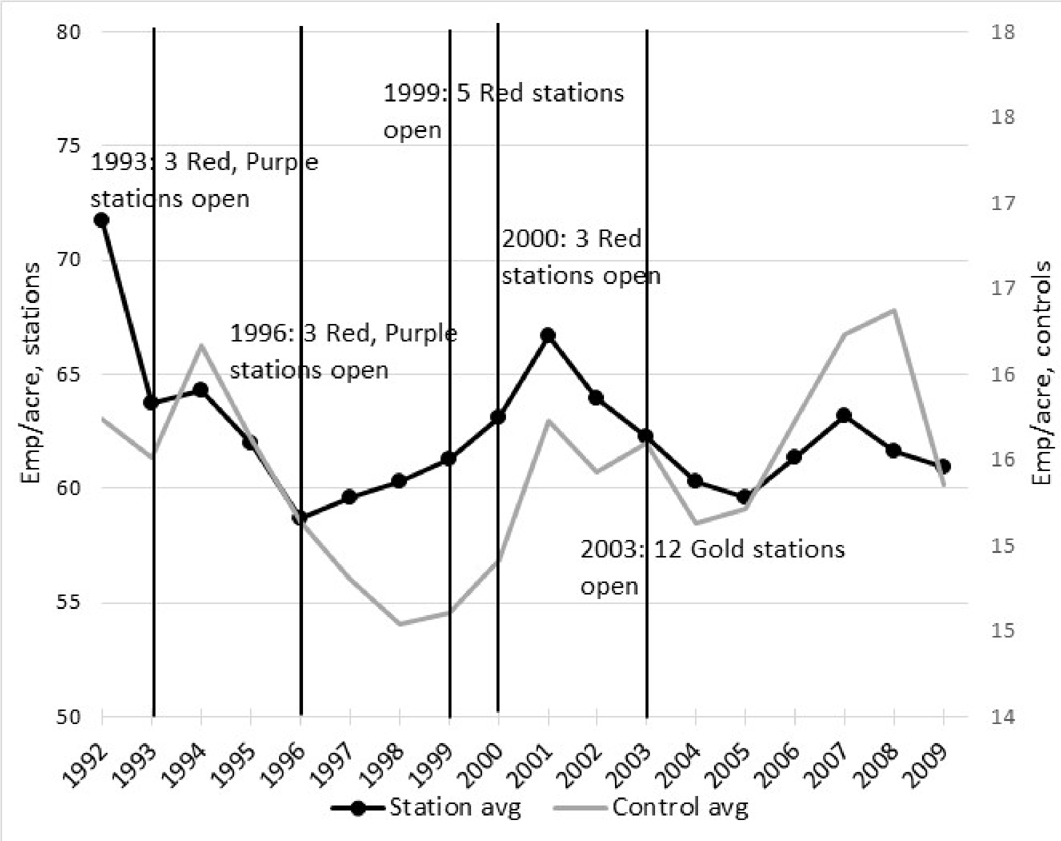
Note: Map shows only Metro stations included in study (excludes Gold Line stations that opened after 2009 and all Blue Line stations). Data assembled from LA Metro, www.metro.net.

Figure 2: Station areas and comparison neighborhoods



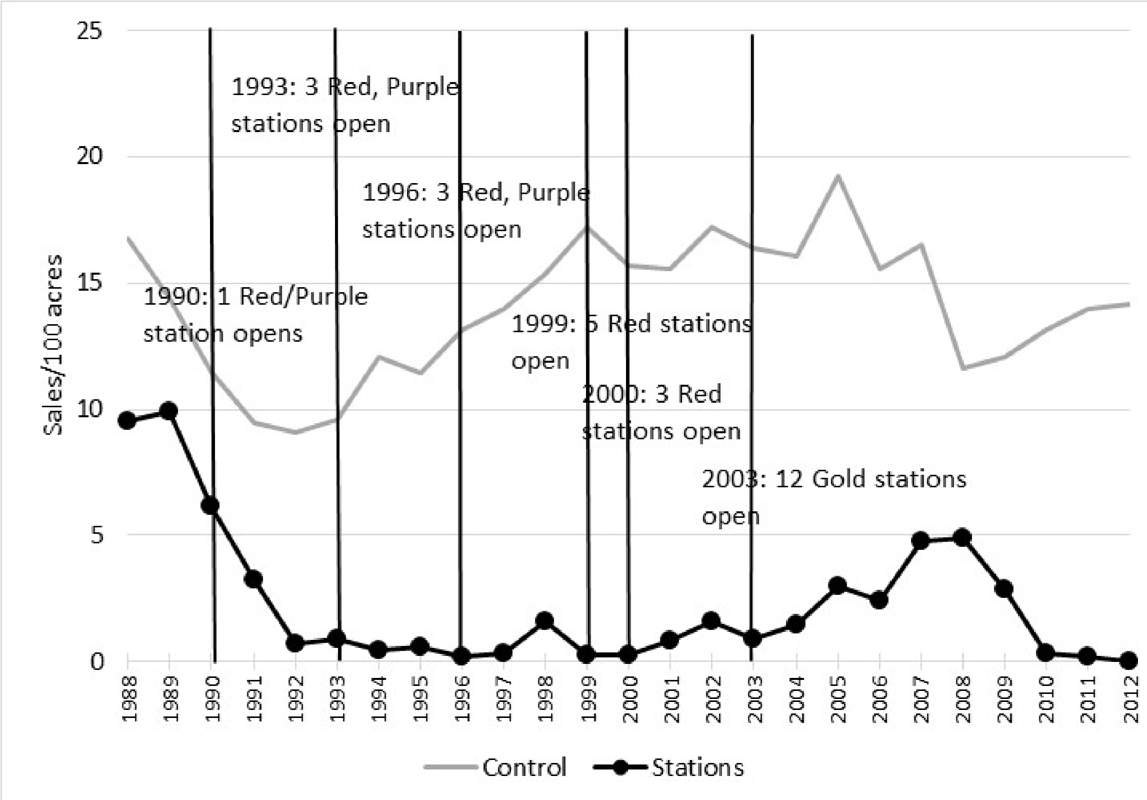
Notes: Data assembled from LA Metro.

Figure 3: Employment in study areas, 1992-2009



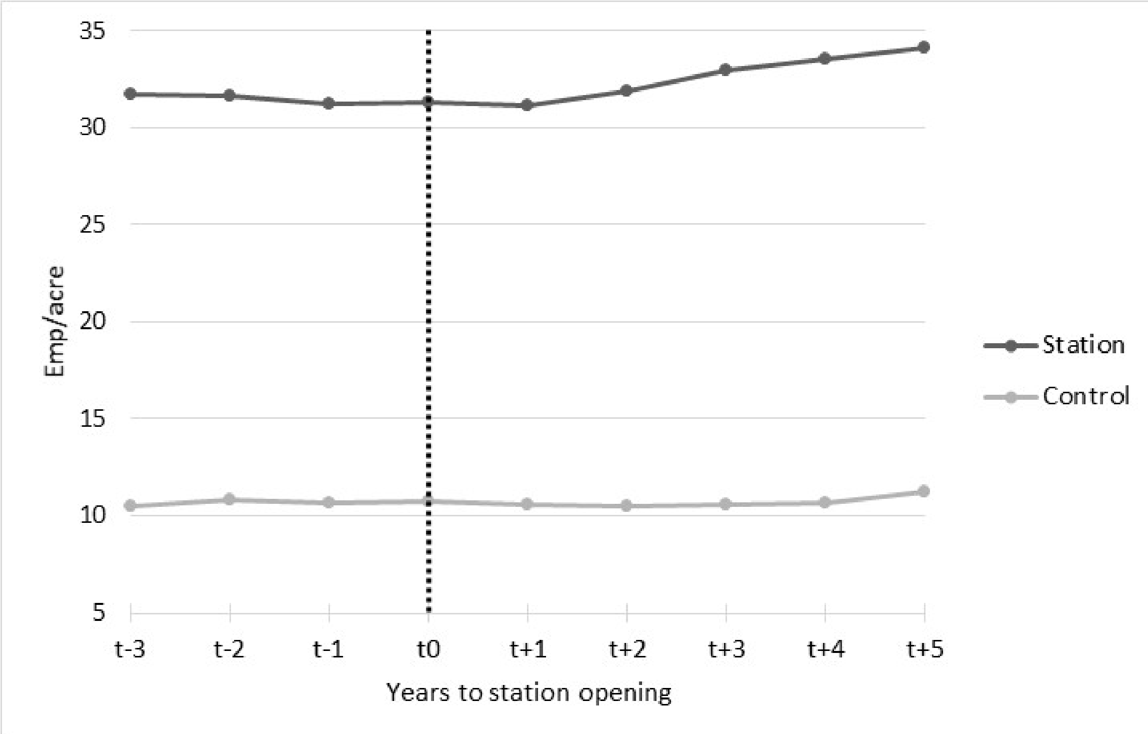
Notes: Calculations based on National Establishment Time Series (NETS) Database. Average employment density per study areas.

Figure 4: Sales volume in study areas, 1988-2012



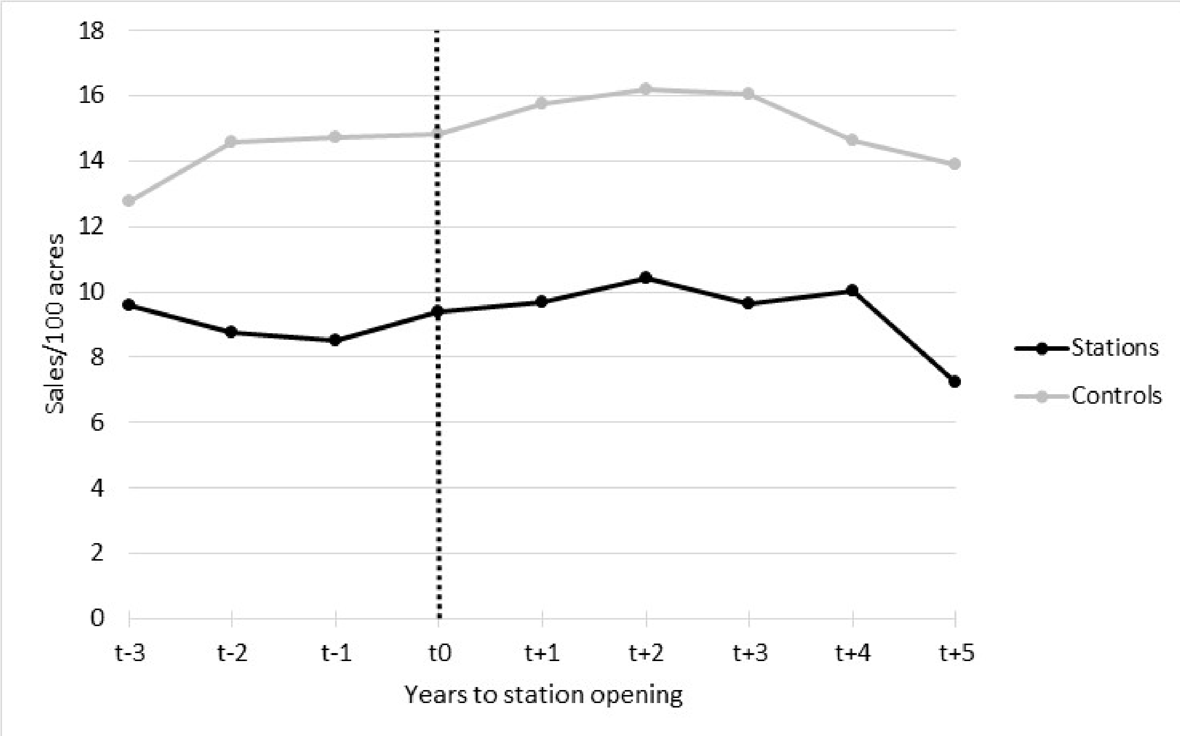
Note: Calculations based on DataQuick housing transaction data. The 7th/Metro Center station opened in 1990 with the inauguration of the Blue Line. Service on the Red and Purple Lines did not begin until 1993 with the completion of the additional stations.

Figure 5: Employment density, pre- and post-station opening



Notes: Calculations based on NETS Database. Excludes three stations that opened in 1993, and matched control areas, because pre-opening employment cannot be observed. Average values for station and control areas shown.

Figure 6: Housing sales volume, pre- and post-station opening



Notes: Calculations based on DataQuick. Average values for station and control areas shown.

Table 1: Mode share for daily journey to work, selected U.S. counties (2006-2010)

County	Rail	Bus	Car	Bike or walk	Other
New York City NY	39.1	12.2	30.0	10.6	8.1
Suffolk MA	17.4	11.6	51.0	14.5	5.6
San Francisco CA	9.7	20.7	47.4	12.4	9.8
Cook IL	6.2	7.4	73.1	4.8	8.6
Los Angeles CA	0.4	5.7	84.3	3.5	6.1
Dallas TX	0.4	2.2	90.6	1.5	5.3
King WA	0.1	9.9	77.7	5.2	7.2

Notes: Calculations based on Ruggles et al (2015), 2006-2010 IPUMS sample of American Community Survey. Rail includes subway, elevated, streetcar and trolley car. Car includes truck and van. New York City includes five constituent counties (Bronx, Kings, New York, Queens and Richmond).

Table 2: Average daily boardings at Metro stations (2013)

Line(s)	Boardings
Gold	1,709
Purple and Red	13,555
Red	7,448
All sample stations	6,733

Notes: Calculations based on data provided by LA Metro. Only stations included in the study are shown. Purple and Red lines include stations that serve both lines, as well as the two stations that serve only the Purple Line (Wilshire/Western and Wilshire/Normandie). Union Station, which serves all three lines, is included in the Purple and Red group.

Table 3: Station opening dates

Year open	# stations	Station name	Lines
1990	1	7th St/Metro Center	Blue, Purple, Red
1992	1	Union Station	Gold, Purple, Red
1993	3	Civic Center, Pershing Square, Westlake/Macarthur Park	Purple, Red
1996	3	Wilshire/Normandie, Wilshire/ Vermont, Wilshire/Western	Purple, Red
1999	5	Hollywood/Vine, Hollywood/ Western, Vermont/Beverly, Vermont/ Sunset, Vermont/ Western	Red
2000	3	Hollywood/Highland, North Hollywood, Universal City	Red
2003	12	Allen, Chinatown, Del Mar, Fillmore, Heritage Square, Highland Park, Lake, Lincoln/Cypress, Memorial Park, Mission, Sierra Madre Villa, Southwest Museum	Gold
TOTAL	28		

Note: Data assembled by authors from LA Metro. When the 7th St/Metro Center station opened in 1990, only the Blue Line was in operation.

Table 4: Station and control areas prior to rail system opening (1990)

	Stations	Control areas	LA County
Employment characteristics			
Emp/acre	66.6	15.8	1.5
Estab/acre	3.49	1.57	0.1
Emp/estab	21.3	14.6	11.6
Employment mix			
Commercial (%)	47.0	41.0	38.1
Industrial (%)	22.7	33.9	37.2
Public/Inst (%)	20.1	18.5	19.0
Misc (%)	7.2	7.8	5.8
Housing market characteristics			
Sales/100 acres	6.2	11.5	na
New units/100 acres	12.0	6.2	na
% sales, single-family	29.7	55.8	na
% sales, condo	26.3	14.2	na
Price/sf (all types)	251.3	255.4	na
Population characteristics			
Pop/acre	111.8	102.3	3.4
Household income	44,017	58,187	75,908
% BA/grad	22.5	23.6	22.3
% black	9.0	9.4	11.2
% Hispanic	42.9	42.2	37.3
% Asian	16.4	14.4	10.5
% pop < 18 yrs	20.31	22.98	26.2

Notes: Calculations based on NETS, DataQuick, and ACS 2005-2009. All numbers for station and control areas are averages per study area. Housing and census variables are measured as of 1990, employment variables as of 1992-94. Prices and incomes reported in constant 2009 dollars.

Table 5: Employment changes, pre- and post-station opening

	Station areas			Control areas		
	Pre	Post	difference	Pre	Post	difference
Emp dens, all sectors	31.5	32.0	0.47	10.6	10.6	-0.07
	(4.0)	(4.0)		(1.0)	(0.9)	
Commercial %	47.5	49.5	1.97	46.6	47.2	0.55
	(2.4)	(2.1)		(1.9)	(1.9)	
Public/inst %	21.8	22.7	0.82	22.0	22.3	0.31
	(2.4)	(2.2)		-(1.7)	-(1.8)	
Industrial %	22.5	19.7	-2.77	22.9	22.3	-0.62
	(1.3)	(1.2)		(1.4)	(1.1)	
Misc %	8.1	8.1	-0.03	8.5	8.2	-0.24
	(0.5)	(0.6)		-(0.8)	-(0.7)	
n	69	69		117	117	

Notes: Excludes 5 stations that opened before 1996 and 9 matched control areas, because we cannot observe three years of pre-opening employment. Standard errors shown in parentheses. None of the differences are statistically significant at 10 percent level or above.

Table 6: Housing market changes, pre- and post-station opening

	Station areas			Control areas		
	Pre	Post	difference	Pre	Post	difference
Sales/100 acres	9.2	10.3	1.11	14.0	16.0	1.98*
	(0.9)	(1.0)		(0.8)	(0.8)	
New units/100 acres	1.0	2.0	0.99	0.7	0.9	0.23
	(0.4)	(1.3)		(0.2)	(0.4)	
% single-family sales	30.4	28.9	-1.50	58.1	54.4	-3.70
	(3.3)	(3.3)		(2.3)	(2.4)	
% condo sales	26.0	29.5	3.52	12.2	13.6	1.36
	(3.7)	(3.8)		(1.8)	(1.9)	
Price/sf (all types)	194.9	344.0	149.1***	189.9	265.4	75.7***
	(10.5)	(22.3)		(6.9)	(12.9)	
n =	47-81	53-81		107-138	118-138	

Notes: Excludes one station and two matched control areas with opening date before 1991, because we lack three years of pre-opening housing outcomes. Number of observations varies by outcome (minimum is for prices, maximum for sales and new units). Standard errors shown in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7: Regression results on employment density, pre- and post-station opening

Dependent variable:	ln(Employees/acre)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Time window	-3 <= t <= 3	-5 <= t <= 5	-5 <= t <= 10	All yrs	-3 <= t <= 3	-5 <= t <= 5	-5 <= t <= 10	All yrs
Station	0.913***	0.851***	0.857***	0.663**	0.892***	0.908***	0.842***	0.850***
	(0.253)	(0.251)	(0.250)	(0.257)	(0.249)	(0.254)	(0.261)	(0.259)
Post	0.092	0.062	-0.002	-0.100				
	(0.177)	(0.179)	(0.150)	(0.110)				
Post*station	-0.041	0.018	0.112	0.344**				
	(0.049)	(0.056)	(0.084)	(0.143)				
YrsPre					-0.057	-0.035	-0.038	-0.007
					(0.088)	(0.086)	(0.086)	(0.085)
Station*YrsPre					0.013	-0.022	-0.003	-0.0511**
					(0.016)	(0.015)	(0.015)	(0.021)
YrsPost					0.038	0.040	0.038	0.046
					(0.090)	(0.089)	(0.085)	(0.083)
Station*YrsPost					-0.005	-0.004	0.0411**	0.0563***
					(0.015)	(0.012)	(0.020)	(0.018)
Observations	434	664	872	1,116	434	664	872	1,116
R-squared	0.301	0.295	0.321	0.299	0.302	0.297	0.327	0.312

All models include year and year-squared, log of population density and income, and group fixed effects. Robust standard errors, clustered by study area, in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 8: Employment density, by industry category

Dependent variable:	% employees in industry category							
Time window:	t-5 to t+5				t-5 to t+10			
Industry category	Commercial	Public/Inst	Industrial	Misc	Commercial	Public/Inst	Industrial	Misc
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Station	5.87	-2.10	-2.60	-1.18	8.324*	-4.09	-3.06	-1.18
	(4.83)	(5.65)	(3.51)	(1.86)	(4.65)	(5.44)	(3.37)	(1.69)
YrsPre	0.71	-2.17	1.08	0.37	0.49	-2.03	1.32	0.22
	(1.61)	(1.58)	(1.06)	(0.97)	(1.57)	(1.57)	(1.02)	(0.85)
Station*YrsPre	0.22	0.01	-0.26	0.04	-0.50	0.60	-0.15	0.05
	(0.36)	(0.43)	(0.41)	(0.17)	(0.41)	(0.48)	(0.40)	(0.20)
YrsPost	-1.08	1.44	0.15	-0.51	-0.65	0.96	0.04	-0.35
	(1.53)	(1.54)	(1.10)	(1.26)	(1.57)	(1.62)	(0.98)	(0.85)
Station*YrsPost	0.56	0.06	-0.59	-0.02	-0.61	1.171**	-0.49	-0.07
	(0.61)	(0.55)	(0.50)	(0.31)	(0.44)	(0.57)	(0.38)	(0.21)
Observations	664	664	664	664	872	872	872	872
R-squared	0.247	0.162	0.138	0.102	0.226	0.154	0.122	0.118

All models include controls for population density, income, year and year-squared, and group fixed effects. Robust standard errors, clustered by study area, in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 9: Employment density, by geographic submarket

Dependent variable:	ln(Employees/acre)							
Time window:	t-5 to t+5				t-5 to t+10			
Sub-market area:	Central LA	North Hollywood	Arroyo Seco	Pasadena	Central LA	North Hollywood	Arroyo Seco	Pasadena
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Station	1.316***	1.542***	-1.320	1.078**	1.318***	1.531***	-1.331	1.080**
	(0.354)	(0.148)	(0.746)	(0.355)	(0.352)	(0.144)	(0.742)	(0.356)
Post	0.169	0.182***	-0.104	0.040	0.148	0.179***	-0.115	0.043
	(0.260)	(0.043)	(0.082)	(0.066)	(0.246)	(0.045)	(0.090)	(0.063)
Post*station	0.008	0.068	0.114	-0.013	-0.007	0.035	0.122	-0.024
	(0.093)	(0.087)	(0.068)	(0.099)	(0.114)	(0.074)	(0.069)	(0.104)
Observations	323	99	99	132	473	135	108	144
R-squared	0.404	0.837	0.411	0.463	0.404	0.849	0.415	0.467

All models include controls for population density, income, year and year-squared. Robust standard errors, clustered by study area, in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 10: Regression results on housing outcomes, pre- and post-station opening

Dep var:	lsales		lnewhsg		Pct SF		lprice	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Time window	-5 <= t <= 5	-5 <= t <= 10	-5 <= t <= 5	-5 <= t <= 10	-5 <= t <= 5	-5 <= t <= 10	-5 <= t <= 5	-5 <= t <= 10
station	-0.442***	-0.469***	-0.030	0.004	-23.71***	-22.27***	0.186***	0.219**
	(0.15)	(0.16)	(0.09)	(0.12)	(5.24)	(5.19)	(0.06)	(0.09)
Year pre	-0.044	-0.041	-0.008	0.003	1.465	1.482	0.0661***	0.0727***
	(0.03)	(0.03)	(0.03)	(0.03)	(1.27)	(1.19)	(0.01)	(0.02)
Station* Year pre	-0.018	-0.015	0.034	0.011	0.948	0.486	-0.0520**	-0.0939**
	(0.021)	(0.022)	(0.043)	(0.050)	(0.648)	(0.588)	(0.022)	(0.037)
Year post	0.034	0.048	0.029	0.0440**	-1.903	-1.445	-0.0607***	-0.018
	(0.034)	(0.033)	(0.021)	(0.018)	(1.508)	(1.426)	(0.013)	(0.012)
Station* Year post	0.005	0.008	-0.003	-0.002	0.981	-0.052	-0.0596***	-0.024
	(0.026)	(0.018)	(0.034)	(0.024)	(0.846)	(0.393)	(0.021)	(0.016)
Observations	801	1,144	801	1,144	713	1,017	576	830
R-squared	0.71	0.69	0.11	0.07	0.49	0.48	0.85	0.73

All models include controls for population density, income, year and year-squared. Models 7-8 also control for age, building size and lot size of properties sold, single-family and condo shares of total sales. Robust standard errors, clustered by study area, in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 1: Industry categories, by 2-digit NAICS

Category	NAICS sector	NAICS2
Commercial		
	Retail Trade	44
	Information	51
	Finance and Insurance	52
	Real Estate and Rental and Leasing	53
	Professional, Scientific, and Technical Services	54
	Management of Companies and Enterprises	55
	Arts, Entertainment, and Recreation	71
	Accommodation and Food Services	72
Industrial		
	Mining	21
	Utilities	22
	Construction	23
	Manufacturing	31
	Wholesale Trade	42
	Transportation and Warehousing	48
	Admin, Support, Waste Mgt & Remediation	56
Public/Administrative		
	Educational Services	61
	Health Care and Social Assistance	62
	Public Administration	92
	Unknown/missing	99
Miscellaneous		
	Agriculture, Forestry, Fishing and Hunting	11
	Other Services	81

Appendix Table 2: Geographic submarkets

Submarket	Stations	# control areas
Arroyo Seco	Heritage Square; Highland Park; Lincoln/Cypress; Mission; Southwest Museum	4
Central LA	Hollywood/Highland; Hollywood/Vine; Hollywood/Western; Vermont/Beverly; Vermont/Santa Monica; Vermont/Sunset; Westlake/MacArthur Park; Wilshire/Normandie; Wilshire/Vermont; Wilshire/Western	25
Downtown LA	7th St/Metro Center; Chinatown; Civic Center; Pershing Square; Union Station	6
North Hollywood	North Hollywood; Universal City	7
Pasadena	Allen; Del Mar; Fillmore; Lake; Memorial Park; Sierra Madre Villa	6

Appendix Table 3: Annual employment density around stations, pre- and post-opening

station	Yr open	emp_pre	emp_post	Emp, t-3	Emp, t-2	Emp, t-1	Emp, t0	Emp, t+1	Emp, t+2	Emp, t+3
7TH ST/METRO CENTER	1990	na	309.5	na	na	na	na	na	329.2	289.7
UNION STATION	1992	na	18.0	na	na	na	18.1	17.5	18.2	18.3
WESTLAKE/MACARTHUR P	1993	na	28.2	na	na	32.2	26.2	29.1	28.3	27.2
PERSHING SQUARE	1993	na	273.6	na	na	305.1	298.6	302.7	267.2	251.0
CIVIC CENTER	1993	na	401.5	na	na	556.5	424.5	422.1	422.2	360.3
WILSHIRE/NORMANDIE	1996	117.5	103.8	123.6	119.1	110.0	104.9	101.6	99.7	110.0
WILSHIRE/VERMONT	1996	105.4	106.3	103.3	105.3	107.7	106.9	104.0	108.5	106.2
WILSHIRE/WESTERN	1996	55.7	59.2	55.5	56.1	55.6	54.5	58.0	59.9	59.6
VERMONT/SANTA MONICA	1999	12.2	16.9	10.2	10.2	16.3	16.1	17.5	17.2	15.9
HOLLYWOOD/WESTERN	1999	7.7	7.2	7.7	7.4	8.0	7.4	6.8	7.9	7.0
VERMONT/BEVERLY	1999	14.9	7.5	16.2	16.0	12.4	10.5	6.9	6.7	9.0
VERMONT/SUNSET	1999	85.6	98.7	91.3	82.0	83.5	84.2	85.6	99.9	110.7
HOLLYWOOD/VINE	1999	68.4	65.8	68.9	72.0	64.3	63.5	67.2	64.9	65.4
UNIVERSAL CITY	2000	36.7	37.7	34.9	36.6	38.4	40.5	41.3	35.0	36.8
NORTH HOLLYWOOD	2000	12.5	13.9	12.2	12.3	12.9	13.6	14.4	13.9	13.5
HOLLYWOOD/HIGHLAND	2000	35.3	41.1	35.2	35.6	35.0	33.7	39.4	41.8	42.2
HIGHLAND PARK	2003	4.5	4.6	4.4	4.7	4.5	4.8	4.7	4.6	4.6
CHINATOWN	2003	21.9	23.6	21.1	22.6	22.0	23.1	22.9	22.7	25.1
HERITAGE SQUARE	2003	3.1	3.1	3.1	3.2	3.1	3.1	3.0	3.2	2.9
MISSION	2003	9.5	10.0	9.9	9.6	9.1	9.9	9.7	10.3	10.0
LINCOLN/CYPRESS	2003	7.9	7.8	8.0	7.3	8.5	8.5	8.2	8.2	7.0
DEL MAR	2003	16.1	16.2	15.6	16.4	16.2	16.2	15.7	16.0	17.0
LAKE	2003	31.1	27.4	30.1	31.2	31.9	35.0	27.2	27.4	27.6
ALLEN	2003	5.1	5.3	4.9	5.2	5.4	5.2	5.5	5.2	5.2
FILLMORE	2003	8.7	14.1	8.5	8.9	8.6	10.4	12.1	14.1	16.2
MEMORIAL PARK	2003	48.9	50.1	50.2	48.4	48.2	50.2	49.4	50.9	50.1
SIERRA MADRE VILLA	2003	14.8	14.2	13.4	15.6	15.3	15.1	14.1	14.4	14.3
SOUTHWEST MUSEUM	2003	1.9	2.0	1.7	1.9	2.0	1.9	1.8	2.0	2.1

Notes: emp_pre and emp_post are average employment densities (emp/acre) for 3-year periods just before and after station opening. The other "Emp, t" numbers are single-year employment densities (per acre). T0 is the opening year in Column 2, t-1 is the year before opening, etc.

Appendix Table 4: Interactions between station and years post-opening

Dependent variable:	ln(Employees/acre)	
	(1)	(2)
Time window	-5 <= t <= 5	-5 <= t <= 10
Station	0.897***	0.896***
	(0.262)	(0.263)
Station*1 yr post	0.005	0.013
	(0.049)	(0.049)
Station*2 yr post	0.047	0.057
	(0.056)	(0.055)
Station*3 yr post	0.058	0.071
	(0.053)	(0.053)
Station*4 yr post	0.048	0.064
	(0.061)	(0.061)
Station*5 yr post	0.037	0.056
	(0.071)	(0.071)
Station*6 yr post		0.012
		(0.074)
Station*7 yr post		0.522**
		(0.227)
Station*8 yr post		0.488**
		(0.226)
Station*9 yr post		0.504**
		(0.221)
Station*10 yr post		0.548*
		(0.279)
Observations	664	872
R-squared	0.265	0.3084

All models include controls for population density, income, year and year-squared. Robust standard errors, clustered by study area, in parentheses. *** p<0.01, ** p<0.05, * p<0.1