Can a Car-Centric City Become Transit Oriented? Evidence From Los Angeles

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Abstract

The urban built environment develops over decades around fixed infrastructure. Los Angeles began its major growth at the dawn of the automobile era and became a low-density, dispersed metropolis organized around a vast freeway system. Since the 1990s, local governments have sought to restructure Los Angeles, shifting toward higher density, mixed-use housing and commercial development. A large investment in new rail transit lines is seen as critical to achieving these land use goals, mainly through promotion of transit-oriented development. In this article, we examine how employment patterns have changed around newly built Los Angeles rail stations. Results suggest that employment did not increase near stations immediately before or after station opening, but a few stations saw increased employment 5 to 10 years after opening.

Introduction

For most of the 20th century, Los Angeles was the quintessential car-oriented city. Over the past 20 years, however, 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 high-density, mixed-use housing and commercial development within walking distance of rail stations, known as transit-oriented development (TOD). By increasing the accessibility of station areas, the building of new stations should increase surrounding land values, leading to higher-density development. In this article, we examine changes in employment patterns around Los Angeles County Metropolitan Transit Authority (LA Metro) rail stations from 1990 to 2010. The analysis examines whether station areas have experienced changes in the density or composition of employment 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 outward in proportion with increasing travel costs (Alonso, 1964; Brueckner, 1987; Mills, 1967; Muth, 1969). Building a rail station that connects the station's neighborhood with the CBD or employment subcenters should increase the accessibility of that neighborhood, thereby increasing land values and encouraging higher density development nearby (Anas, 1995; Glaeser and Kohlhase, 2004). Neighborhoods around rail stations should be relatively more attractive both to firms and households. Firms can attract more workers due to increased accessibility, as well as more consumers to convenient locations, particularly in household-serving industries such as retail, food service, and healthcare. Households will be willing to pay higher housing prices in exchange for lower transit costs.

How much land values and economic activity increase near stations depends 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. Because most passengers access rail stations by walking, station effects will be highly localized. Prior research has also posited some potential negative impacts of rail stations on nearby areas. Rail stations may increase noise, traffic congestion, or crime in the adjacent area; these nuisances are likely stronger disamenities for households than for commercial uses. Land values around stations may fluctuate in the short run, both prior to and immediately after opening, before reaching long-run equilibrium. The relationship between short-run and long-run land values is somewhat ambiguous. For instance, anticipation of increased demand may cause short-run spikes in land values, beyond prices that developers are willing to pay, which can deter or delay development. This is particularly likely if small parcel owners become "holdouts" (Brooks and Lutz, 2016). Conversely, developers may perceive untested locations as excessively risky and delay undertaking projects until some first-mover demonstrates actual profits (essentially underestimating long-run land values in the short run).

A broad empirical literature has attempted to identify the impacts of rail transit investments on outcomes such as transit ridership, land values, housing prices, population and housing density, employment composition, population characteristics, and crime (Baum-Snow and Kahn, 2005; Billings, 2011; Billings, Leland, and Swindell, 2011; Boarnet and Crane, 1997; Bollinger and Ihlanfeldt, 1997; Bowes and Ihlanfeldt, 2001; Cervero and Landis, 1997; Debrezion, Pels, and Rietveld, 2007; Dubé, Thériault, and Des Rosiers, 2013; Giuliano and Agarwal, 2010; Handy, Cao, and Mokhtarian, 2005; Kahn, 2007; Lin, 2002; Mathur and Ferrell, 2013; McMillen and McDonald, 2004; Poister, 1996; Renne and Ewing, 2013; Winston and Maheshri, 2007). As well as measuring different outcomes, these studies cover different cities, time periods, and transit types (heavy rail, light rail, and streetcar). Results from these studies are somewhat mixed, although one relatively consistent finding is that the extent of changes in property values, employment, and related economic outcomes depends on the level of transit ridership; low ridership on average produces smaller impacts.

Only a few prior studies have examined the LA Metro system, which is new relative to "legacy" systems such as those in New York City, Boston, and Chicago, or even second-wave subways such as the Bay Area Rapid Transit (BART) in the San Francisco Bay Area and Washington, D.C.'s Metro. Kolko (2011) and Schuetz (2015) examined employment near newly opened rail stations in Los Angeles and several other large California metropolitan areas; both find little change in employment levels near stations. Redfearn (2009) found no average change in housing prices near Los Angeles rail stations but furthermore found that the average conceals substantial variation in housing price changes across stations. Similarly, in a qualitative study of physical redevelopment near five LA Metro stations, Schuetz, Giuliano, and Shin (2017) found that TOD is emerging unevenly across station neighborhoods. Areas that experienced changes in land use or buildings have strong localized real estate markets, have zoning that allows high-density residential and commercial development, and benefited from highly targeted local government engagement. Weak property values and incompatible zoning both contribute to lack of redevelopment near some stations.

This article 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, services, and related activities are key components of TOD. Second, we are able to conduct longitudinal analysis of treatment and control areas over a 20-year period, which allows us to test for prestation anticipation effects and lagged changes. Third, impacts of transit in Los Angeles have been less studied than in many other cities. Los Angeles' 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 rail and streetcar investment in many U.S. cities, including Charlotte, Cincinnati, Denver, and Washington, D.C.

In this analysis, we combine data on the location and opening dates of 28 rail stations in Los Angeles County with establishment-level employment data. We measure the level and industrial composition of employment within 0.25- and 0.5-mile catchment areas of newly opened rail stations, before and after opening. As a comparison group, we identify a set of major road intersections in the same neighborhoods as stations but outside direct catchment areas. We use a difference-in-differences approach to compare changes in employment outcomes before and after opening for station and control areas. Results indicate that the areas selected for new stations had unusually high employment density prior to station opening. No evidence suggests that employment near stations changed within 5 years before or after station opening, but some results suggest that a few stations experienced increased employment within a 5- to 10-year period after opening. One possible explanation for the long lag is that most stations were built in already densely developed areas, where redevelopment is costly and slow. Alternatively, proximity to stations may become more valuable as the network size expands through additional lines.

Our results offer two key insights to transit planners who are building or expanding rail networks in other metropolitan areas, particularly car-oriented cities with multiple employment centers and a dense urban fabric. First, transit infrastructure is more likely to deliver long-run benefits than short-run stimulus. Second, planners should be clear about the primary goal of building rail systems—weighing access to existing jobs versus stimulating new residential development—when choosing station locations and coordinating housing or land use policies.

The remainder of this article 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.

Background on Los Angeles Rail Network

Even after roughly $9 billion (nominal) of public investment in rail infrastructure, Los Angeles remains a car-oriented city (Nelson and Weikel, 2016). As of the late 2000s, 84 percent of the city's residents commuted to work by car, with fewer than 7 percent using mass transit (exhibit 1). Even among transit riders, over 90 percent of commuters relied on buses rather than rail; these market shares have not changed appreciably since rail service began in 1990. The relatively low ridership 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 and increased employment. 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. LA Metro stations are relatively thinly spread across a large geographic area (exhibits 2 and 3); 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 even when considering using bus service to transfer to the nearest rail station.

One means of illustrating the demand for rail stations is the number of daily boardings (exhibit 4). 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 in downtown and central Los Angeles draw the most riders, with over 13,500 average boardings per day, compared to about 1,700 boardings at the Gold Line stations in Pasadena and the Arroyo Seco corridor north of downtown. Connectivity to the broader network is correlated

Exhibit 1

Mode Share for Daily Journey to Work, Selected U.S. Counties (2006–2010)

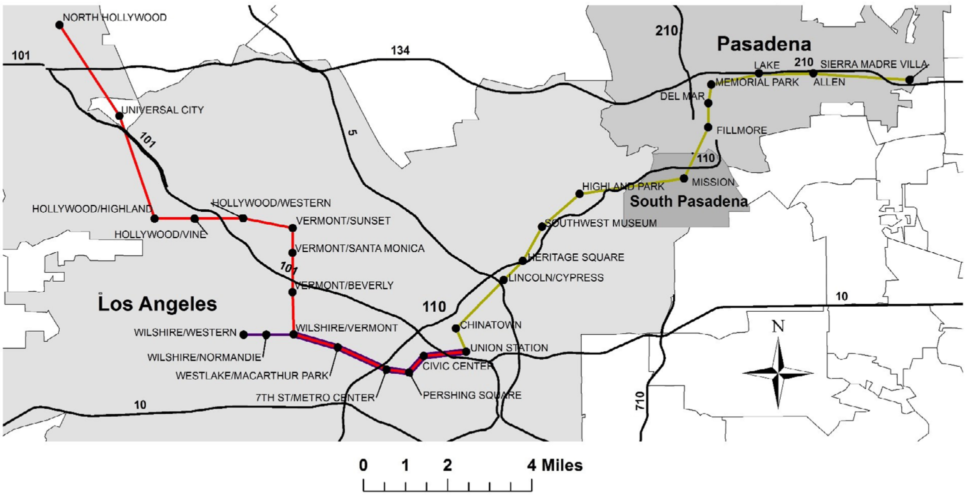
County	Rail	Bus	Car	Bike or Walk	Other
New York City, New York	39.1	12.2	30.0	10.6	8.1
Suffolk, Massachusetts	17.4	11.6	51.0	14.5	5.6
San Francisco, California	9.7	20.7	47.4	12.4	9.8
Cook, Illinois	6.2	7.4	73.1	4.8	8.6
Los Angeles, California	0.4	5.7	84.3	3.5	6.1
Dallas, Texas	0.4	2.2	90.6	1.5	5.3
King, Washington	0.1	9.9	77.7	5.2	7.2

Notes: 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).

Source: Calculations based on Ruggles et al. (2015), 2006–2010 Integrated Public Use Microdata Series sample of American Community Survey

Exhibit 2

Study Area Metro Stations

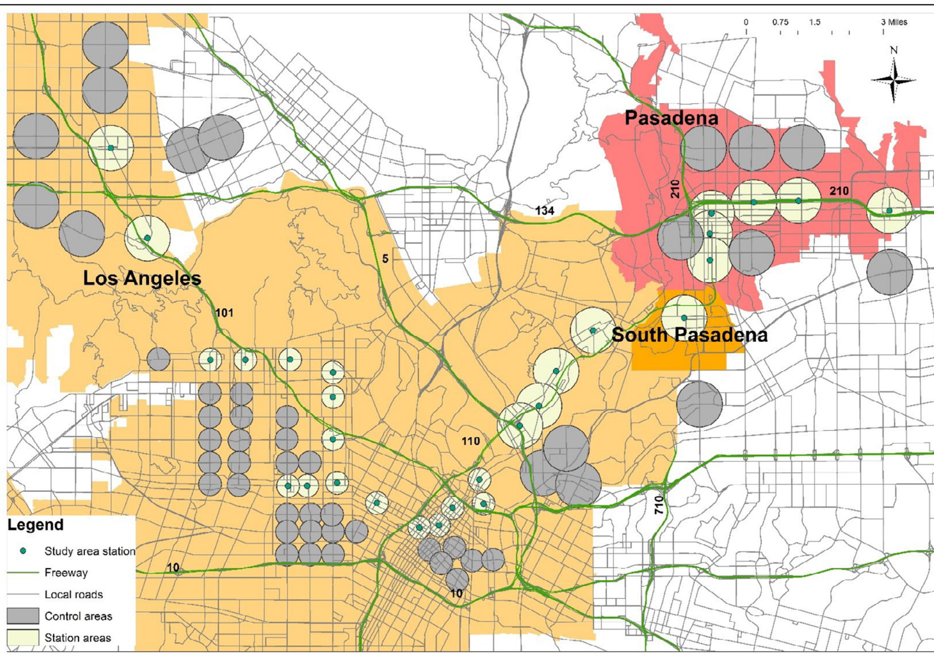


Note: Map shows only Metro stations included in study (excludes Gold Line stations that opened after 2009 and all Blue Line stations).

Source: Data assembled from Los Angeles County Metropolitan Transit Authority

Exhibit 3

Station Areas and Comparison Neighborhoods



Source: Data assembled from Los Angeles County Metropolitan Transit Authority

Exhibit 4

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: 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.
Source: Calculations based on data provided by Los Angeles County Metropolitan Transit Authority

with ridership. The stations with the three highest number of daily boardings are Union Station (over 34,000), which serves the three Metro lines, as well as the Metrolink commuter rail system and Amtrak; 7th St/Metro Center (27,000), serving the three Metro lines and several major bus lines; and North Hollywood (17,000), which connects the Red Line rail to a 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 at the time of the study 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 0.5-mile catchment estimated for walking.[1] 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 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 economic institutions throughout the region.[2] The general direction of each line, as well as the placement of some stations, reflect compromises along multiple dimensions. For instance, the Blue Line between Los Angeles and Long Beach was built first because of several political and fiscal 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, 2014). The Green Line was built down the middle of Interstate 105 as part of a consent decree resolving a lawsuit over the freeway's construction (Elkind, 2014). The subway lines from downtown Los Angeles to Hollywood and the San Fernando Valley were the most controversial

[1] Commuters who bike to rail stations may also originate from a larger catchment area.

[2] The lengthy and complex planning and development process was minutely documented in Elkind (2014). Taylor, Kim, and Gahbauer (2009) examined political influences for the Red Line. In this article, we briefly summarize a few of the general factors and examples that illustrate why rail station areas are systematically different than control areas.

routes. 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. However, 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, 2014; Taylor, Kim, and Gahbauer, 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 (Elkind, 2014). Similarly, the stations in Hollywood were supported by the local chamber of commerce, which welcomed the potential revitalization of a declining area (Elkind, 2014). 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. 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 LA Metro'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. 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 well before the rail stations opened.[3]

Data Sources and Empirical Approach

We analyze changes in employment density and composition around 28 rail stations that opened in Los Angeles County between 1992 and 2003. As a comparison group, we identify a set of intersections located more than 0.5 mile but within 3 miles of the rail stations. The analysis uses several variations on a difference-in-differences framework to test whether employment changed near rail stations after station opening, relative to control areas. We test for differences before and after opening, as well as variation over time before and after opening.

Data Sources

The location and opening dates of rail transit stations were assembled from the LA 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

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

each station was also assembled. The research focuses on 28 stations along the Red, Gold, and Purple Lines, for which we have sufficient data on preopening and postopening outcomes.[4]

Data on business establishments come from the National Establishment Time Series, or NETS, database, which contains the business name, address, North American Industry Classification System (NAICS) industry code, and number of employees for all business establishments from 1992 to 2009. Outcomes of interest are the total number of jobs near stations and the mix of jobs by industry category.

General economic and demographic characteristics on station and control areas are 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 0.25 or 0.5 mile, while control areas are similar-sized circles around major intersections, described in more detail in the following section. 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.

Empirical Approach

The research design compares changes in housing and employment outcomes near newly opened rail stations, before and after opening. As shown in exhibit 5, study-area stations offer sufficient variation in timing to allow analysis of 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 the city of South Pasadena. Treatment areas are defined as circles of either 0.25- or 0.5-mile radius from the rail station, which prior literature has shown is the typical catchment area for rail transit ridership (Guerra and Cervero, 2013; Hess and Almeida, 2007; Kolko, 2011; McDonald and Osuji, 1995). We use 0.25-mile radius for Red and Purple Line stations, because these stations are located closely together, and 0.25 mile yields mostly nonoverlapping treatment areas. The Gold Line stations and Red Line stations in North Hollywood are located farther from one another, so we use 0.5-mile radius as the treatment area for those stations.[5]

[4] The Blue Line stations opened in 1990, before our employment data are available, whereas the Expo Line and some Gold Line stations are too recent for us to observe poststation outcomes. The Green Line is excluded because most stations are in the freeway median, making development immediately adjacent to the stations impossible. Descriptive statistics include all 28 stations, but regression analysis excludes the 5 stations that opened prior to 1996, because we do not observe at least 3 years of preopening employment.

[5] The 0.5-mile treatment areas around three downtown Pasadena stations do overlap, but the 0.5-mile catchment area was deemed more appropriate, given the presence of onsite 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.

Exhibit 5

Station Opening Dates

Year Open	Number of Stations	Station Name(s)	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: When the 7th St/Metro Center station opened in 1990, only the Blue Line was in operation.
Source: Data assembled by authors from Los Angeles County Metropolitan Transit Authority

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 LA Metro station locations were selected based largely on political and fiscal compromises, which may not correspond to the most economically or geographically efficient sites. Nonetheless, station locations likely differ from all nonstation areas in Los Angeles County in ways that can affect subsequent development. Therefore, we defined comparison areas based on several criteria designed to control for important preopening differences. First, comparison areas should be more than 0.5 mile from any rail station (new, existing, or future) so they will not directly be affected by the station. Second, they should be located within 3 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, 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).

This approach offers two advantages over other matching methods, such as propensity score matching (PSM). First, our treatment areas—circular areas within walking distance of transit stations—do not correspond to conventionally defined geographic areas such as census tracts or block groups. (Indeed, most stations are located at the intersection of multiple census tracts, so any single tract or block group captures only a fraction of the relevant area.) Therefore, no set of predefined geographies not affected by stations could serve as potential control areas to be used in an automated matching process. Second, the underlying rationale for why station areas should see increased economic activity is that they benefit from particularly high accessibility to a larger transit network. The major intersections where stations are located tend to have greater access for automobiles, buses, and pedestrians, as well as trains. Choosing control areas that share similar road access allows us to control for the nonrail access of the comparison sites, in a way that would be difficult to capture accurately using PSM or similar methods.

Exhibits 2 and 3 show the location of the 28 station areas and 48 comparison areas in the study. The stations form a rough triangle among the North Hollywood Station (northwest corner), 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, assigned to five geographic submarkets: Arroyo Seco, Central Los Angeles, Downtown Los Angeles, North Hollywood, and Pasadena.

We begin with a set of graphs and descriptive statistics, illustrating the levels and changes in employment 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).

$$Y_{it} = \beta_0 + \beta_1 Station_i + \beta_2 Post_{it} + \beta_3 Post{*}Station_{it} + \beta_4 X_{it} + \beta_5 Submkt_j + \varepsilon_{it} \qquad (1)$$

In this equation, *i* indexes the study area, *t* indexes the year. *Y* is a measure of employment. *Station* is a dummy indicating station areas. We look at both employment 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 the appendix for NAICS two-digit sectors assigned to the four industry categories). *Post* is a dummy variable that equals 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 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.[6] Fixed effects for geographic submarkets described previously are also included.

The before-and-after opening framework may obscure an important question: do employment patterns vary differently across years, either before or after station opening? Several of the hypotheses about how outcomes might vary over time would not be captured by a simple before-and-after analysis. Some studies of new rail lines in other cities have found an "anticipation effect," in which real estate prices near stations increase after the locations have been announced but well before the stations begin operating (Billings, 2011; McMillen and McDonald, 2004). For impacts to begin appearing soon after the announcement, it is necessary that landowners or developers have reasonably certain expectations that stations will indeed be built at the announced locations, in a time frame that justifies current investment.[7] However, in the case of Los Angeles, it is unclear

[6] 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.

[7] In Chicago, the line in question was an expansion of the already well-utilized system, adding a connection from downtown to Midway airport (McMillen and McDonald, 2004). In Charlotte, the city government revised the zoning and land use planning to maximize growth potential around a new light rail system (Billings, 2011). In both cases, the announcement of specific locations was followed relatively soon by appropriation of funds and the start of construction.

whether the conditions for anticipatory investment were present. The earliest plans suggesting rail line pathways emerged in the early 1970s, but federal and local funding for construction remained highly uncertain until the mid-1980s. The location of stations along the Red and Purple Lines was highly contentious, with multiple plans proposed and political jockeying for and against, until shortly before construction began (Elkind, 2014). In practice, we are unable to test for changes in employment before and after the announcement date, or around the date that funding was secured, because our employment data do not extend back far enough. Given the demonstrated reliance of Los Angeles commuters on cars, demand for rail transit—particularly for early stations—will be particularly uncertain. Thus it seems plausible that 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 observe the volume of transit riders and effectiveness of the new rail line. In this case, there may be a substantial delay before aggregate economic patterns change. To test for varying employment patterns over time, we estimate the following regressions, shown in equation (2).

$$Y_{it} = \beta_0 + \beta_1 Station_i + \beta_2 YrsPre_{it} + \beta_3 Station*YrsPre_{it} + \beta_4 YrsPost_{it} + \beta_5 Station*YrsPost_{it} + \beta_6 X_{it} + \beta_7 Submkt_j + \varepsilon_{it} \quad (2)$$

In this equation, *YrsPre* is a continuous numeric variable indicating the number of years prior to station opening (equal to 0 for all years after opening), *YrsPost* is the count of years after station opening (equal to 0 for all years prior). The interaction term, *Station*YrsPost*, gives the coefficient of interest, indicating the difference in employment associated with each year after opening for station areas, relative to control areas. Regressions include the same control variables, year polynomial terms, and fixed effects for geographic submarkets.[8]

The regression analysis implicitly tests the hypothesis that increases in land values due to station areas' improved accessibility will result in higher density of 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 new housing or employment could emerge near the station, even if firms and developers wished to locate nearby. Alternatively, if 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. Because zoning and other public interventions may either constrain or enhance development, and prior research has found that zoning differs substantially across LA Metro stations (Schuetz, Giuliano, and Shin, 2017), it seems likely that not controlling for local policies will introduce measurement error but will not consistently bias our results.

Results

The locations in which new rail stations were built during the 1990s and 2000s had unusually high employment densities prior to station opening. Employment densities around station and

[8] As a robustness check, we also estimate regressions with a full set of dummy variables for each year before and after opening. Results of the fully interacted model are substantively similar to the simpler interactions with continuous number of years; results available from authors on request.

control areas fluctuated somewhat over time with macroeconomic cycles, but there is no clear time trend. Descriptive statistics and regressions both indicate that station areas did not see employment growth within 3 years before or 5 years after station opening. Regression results suggest that a few stations that opened between 1996 and 1999 saw significant employment gains between 5 and 10 years after stations opened.

Descriptive Statistics: Employment Metrics

A substantial difference between the rail system in Los Angeles and those in older cities such as New York City and Boston is that land use and employment patterns were well-established before Los Angeles' rail stations were built. As noted in the second section, rail lines were intended to connect existing employment centers, enhancing access of potential workers to job-rich areas. An analysis of preopening 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 (exhibit 6). The average station area had nearly 70 employees per acre as of 1992, four times the employment density in control areas; excluding stations and control areas in downtown Los Angeles, station areas had on average 34 employees per acre, compared to 11 employees per acre 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 than 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 (NAICS codes 44 and 45) and healthcare and social assistance (NAICS code 62) each make up 10 to 12 percent of employment. Beyond those sectors, employment near stations was more weighted

Exhibit 6

Station and Control Areas Prior to Rail System Opening, 1990

	Station Areas	Control Areas	Los Angeles County
Employment characteristics			
Employees per acre	66.6	15.8	1.5
Establishments per acre	3.49	1.57	0.1
Employees per establishment	21.3	14.6	11.6
Employment mix			
Commercial (%)	47.0	41.0	38.1
Industrial (%)	22.7	33.9	37.2
Public/institution (%)	20.1	18.5	19.0
Miscellaneous (%)	7.2	7.8	5.8
Population characteristics			
Population per acre	111.8	102.3	3.4
Household income ($)	44,017	58,187	75,908
Bachelor's/graduate degree (%)	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
Younger than 18 (%)	20.31	22.98	26.2

Notes: 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 1992–1994. Prices and incomes reported in constant 2009 dollars.

Sources: Calculations based on National Establishment Time Series database, DataQuick, and American Community Survey 2005–2009 toward 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 toward industrial sectors, mostly wholesale trade and manufacturing, which tend to be located in buildings with lower floor-to-area ratios.

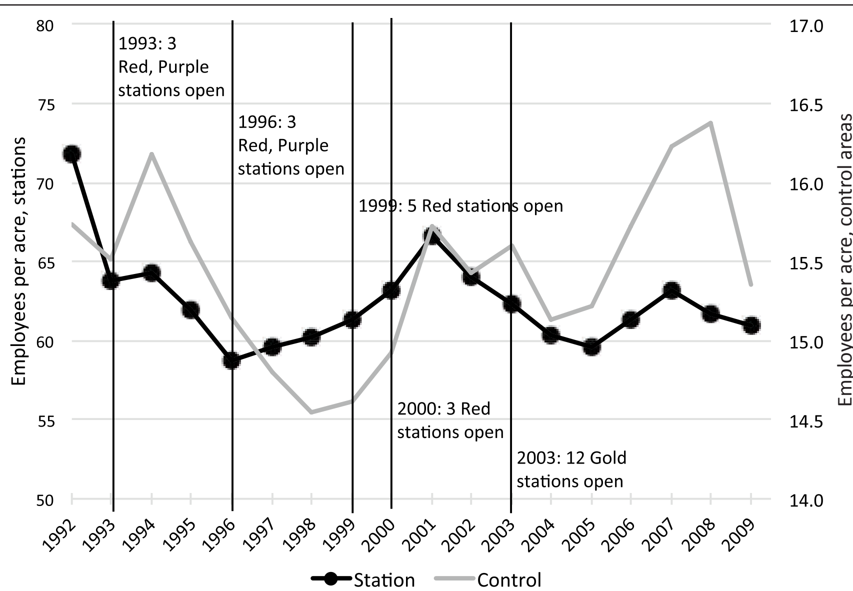
Station and control areas differed somewhat in population characteristics, prior to development of the rail network, but these differences are less pronounced than the prestation differences in employment. Both station and control areas had higher population densities than Los Angeles County overall. 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 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 standard 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. Lower incomes in station areas may suggest that those areas were initially less attractive sites for new development, or that residents would welcome additional jobs and services. Thus, it is unclear whether and in what direction preexisting differences might bias regression results.

Exhibit 7 shows average employment density 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

Exhibit 7

Employment in Study Areas, 1992–2009

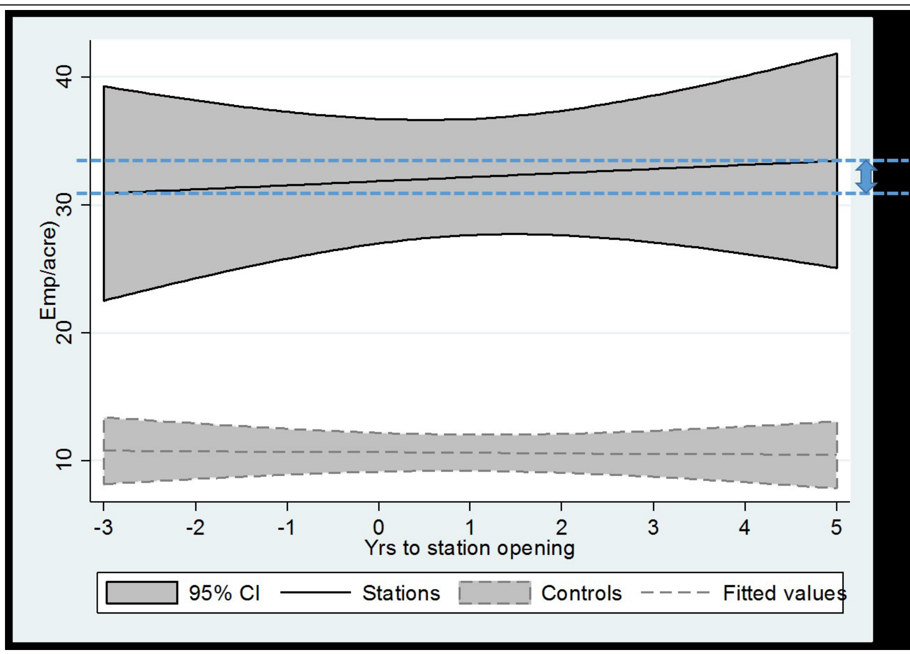


Source: Calculations based on National Establishment Time Series database from changes in general economic conditions. Average employment densities in both station and control areas show some cyclical movements between 1992 and 2009, decreasing during the recessions of the early 1990s, early 2000s, and in the Great Recession from 2007 to 2009 (exhibit 7). 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 among the study areas, nor does the graph show clear visual evidence of employment changes around station opening dates.

To focus more clearly on the time periods of interest, exhibit 8 shows average annual employment density, beginning 3 years before station opening and ending 5 years after station opening. The employment analysis includes only the 23 stations and matched control areas for which at least 3 years of preopening employment data are available.[9] The year of opening is defined for each station/control area, so that t_0 represents different years for each cluster of stations/controls. Although average employment density levels differ substantially between stations and control areas, the time trends before opening are quite similar; employment is virtually flat during the prestation years and for 1 year afterward (exhibit 8). Station areas show a modest increase between years 2 and 5, from about 32 employees per acre to about 34 employees per acre. Control areas have flat employment

Exhibit 8

Employment Density, Before and After Station Opening



CI = confidence interval.
Notes: Average values and 95-percent confidence intervals for station and control areas. Excludes three stations that opened in 1993 and matched control areas.
Source: Calculations based on National Establishment Time Series database

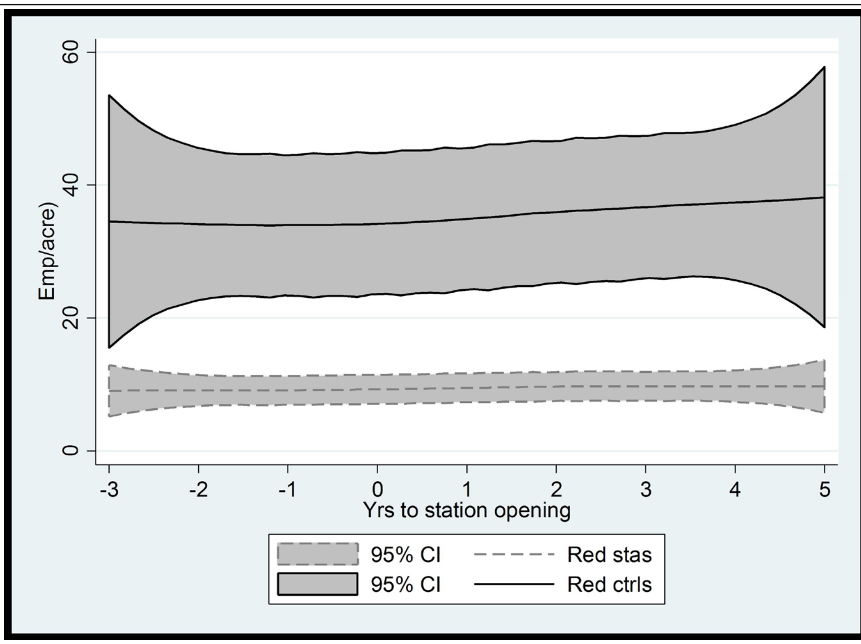
[9] Dropping the three earliest Red and Purple Line stations reduces the average employment density among stations by roughly one-half, from about 60 employees per acre to about 30, because the earliest stations include the highest density employment centers in downtown Los Angeles.

density through year 3 after station opening, then an increase of slightly less than 1 employee per acre from years 3 through 5. Both station and control areas have fairly wide 95-percent confidence intervals around the estimated line, suggesting that the slopes are not significantly different than 0.

The three rail lines in our sample differ by opening year, and run through different parts of the city, so the averages for all stations may conceal differences in time trends across lines. Exhibits 9 and 10 show employment density before and after opening for stations and controls along the Red and Gold Lines.[10] Employment densities around Red Line stations and controls are trending slightly upward during the 8-year window around station opening, but the slopes are not significantly different from one another, and there is no indication of a change in slope after opening (exhibit 9). Gold Line stations have employment densities close to their control areas, and show different time trends; employment is trending upward around station areas and downward near control areas (exhibit 10). However, the confidence intervals for both station and control areas are quite wide and almost completely overlap, so we cannot infer significant differences between them from the graphs. Neither stations nor controls show changes in slope after station opening. Replicating exhibits 8 through 10 for longer time intervals show similar patterns (results available from authors by request).

Exhibit 9

Employment Density Around Red Line Areas, Before and After Station Opening

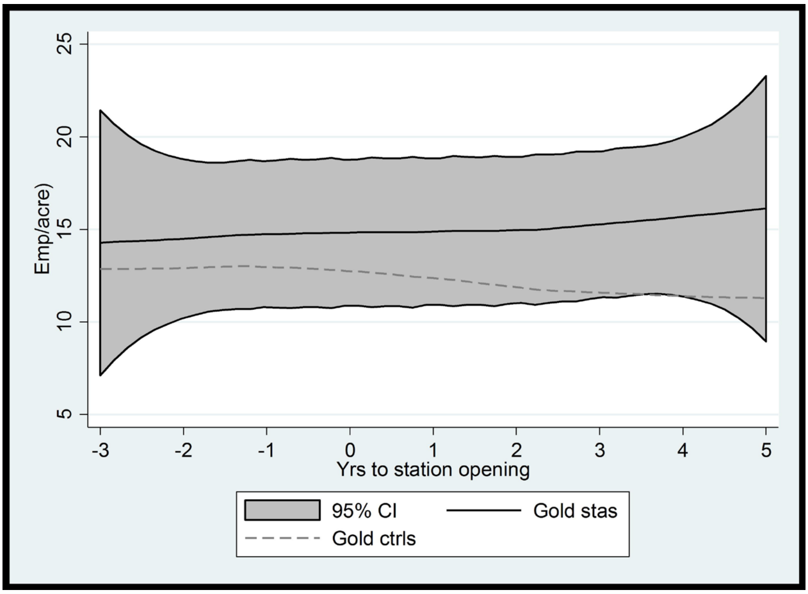


CI = confidence interval.
Notes: Average values and 95-percent confidence intervals for station and control areas. Excludes three stations that opened in 1993 and matched control areas.
Source: Calculations based on National Establishment Time Series database

[10] Only three stations on the Purple Line have 3 years of preopening employment data.

Exhibit 10

Employment Density Around Gold Line Areas, Before and After Station Opening



CI = confidence interval.
Notes: Average values and 95-percent confidence intervals for station and control areas. Excludes three stations that opened in 1993 and matched control areas.
Source: Calculations based on National Establishment Time Series database

Before estimating regressions, we compare our main employment outcomes for the 3 years before and after station opening. We calculate average employment density and share of employment in each of the four industry categories for station and control areas over 3 years, before and after opening (exhibit 11). Using a 3-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.[11] None of the five employment outcome variables show significant changes from the 3 years prior to station opening to the 3 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 0 or substantively large in magnitude. The largest change is a nearly 3-percentage-point decrease in industrial employment share, but this is also not statistically significant. Among control areas, overall employment density is essentially the same before and after opening years of the matched station areas, and there are no significant changes in employment composition. Consistent with exhibits 7 through 10, results indicate substantially higher employment levels around stations than in control areas, but do not indicate changes in employment levels shortly after station opening.

[11] 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. No observable time trends are within the 3-year windows, nor does apparent variation occur in time trends across stations. The annual data are 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.

Exhibit 11

Employment Changes, Before and After Station Opening

	Station Areas			Control Areas		
	Preopening	Postopening	Difference	Preopening	Postopening	Difference
Employment density, 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/institution (%)	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)	
Miscelleaneous (%)	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 five stations that opened before 1996 and nine matched control areas, because authors cannot observe 3 years of preopening employment. Standard errors shown in parentheses. None of the differences are statistically significant at the 10-percent level or above.

Regression Results: Employment Changes

As a more rigorous test of whether employment around stations changed after stations opened, we estimate a series of regressions summarized in exhibit 12. We estimate preopening and postopening differences for three time windows: (1) 3 years before station opening to 5 years after, (2) 5 years before to 10 years after, and (3) 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 preopening employment.[12]

Regression results generally confirm the findings from graphs and descriptive statistics: station areas had higher initial employment density than control areas, and saw no immediate changes in employment following station openings. However, there is some evidence that employment may increase in the 5- to 10-year window after stations open. In the simple before-and-after analysis (columns 1 through 3), the coefficient on *Post*Station* increases in magnitude as the time window around station opening expands, only becoming statistically significant when including all years (column 3). The magnitude suggests a 34-percent increase in employees per acre (from an average of 67 prior to opening) over the entire duration of poststation years. However, we can only observe 10 years of postopening employment for eight stations, up to 9 years of postopening employment for another three stations, while we observe at most 6 years of postopening employment for the 12 Gold Line stations. This suggests that the employment gains discerned in the regression occur for the stations that opened from around 1996 to 1999, and became evident toward 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.

[12] Estimating the regressions for variations on these time windows, including 3 years prior to opening to 5 or 10 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.

Exhibit 12

Regression Results on Employment Density, Before and After Station Opening

Dependent Variable	ln(Employees/Acre)			ln(Employees/Acre)		
	(1)	(3)	(4)	(5)	(7)	(8)
Time window	$-3 \le t \le 5$	$-5 \le t \le 10$	All yrs	$-3 \le t \le 5$	$-5 \le t \le 10$	All years
Station	0.906***	0.857***	0.663**	0.883***	0.842***	0.850***
	(0.254)	(0.250)	(0.257)	(0.251)	(0.261)	(0.259)
Post	0.079	– 0.002	– 0.100			
	(0.171)	(0.150)	(0.110)			
Post*station	– 0.030	0.112	0.344**			
	(0.056)	(0.084)	(0.143)			
YrsPre				– 0.052	-0.038	– 0.007
				(0.089)	(0.086)	(0.085)
Station*YrsPre				0.014	– 0.003	– 0.0511**
				(0.016)	(0.015)	(0.021)
YrsPost				0.036	0.038	0.046
				(0.089)	(0.085)	(0.083)
Station*YrsPost				– 0.004	0.0411**	0.0563***
				(0.011)	(0.020)	(0.018)
Group fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	558	872	1,116	558	872	1,116
R-squared	0.296	0.321	0.299	0.297	0.327	0.312

*** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Notes: 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.

Next we estimate a parallel set of regressions using continuous number of years before and after station opening (exhibit 12, columns 4 through 6). Results are very similar to those using a binary indicator for after opening: the coefficient on *Station*YrsPost* does not become positive and significant until the study window includes up to 10 years after opening (column 5), and increases in both magnitude and significance when using the full set of years (column 6). The magnitudes of the coefficients suggest a 4- to 6-percent increase in employment per acre each year after opening, with most of this coming from the early-opening stations in the 5 to 10 years afterward. These annual numbers are roughly consistent with the 34-percent increase for all poststation years from column 3.

The example of the Hollywood and Vine station on the Red Line illustrates why development may substantially lag station opening. The Los Angeles Community Redevelopment Agency used eminent domain to assemble parcels near the station, enabling LA Metro to undertake a large-scale redevelopment project, complete with high-density multifamily housing, a hotel, and ground-floor commercial uses (Schuetz, Giuliano, and Shin, 2017). Even with unusually concerted efforts by public agencies, the redevelopment project was completed in 2009, 10 years after the station opened. This example raises questions about how quickly redevelopment may become apparent in aggregate data. Because we only observe 10 years of postopening data for a few stations, we cannot infer whether the lag reflects true redevelopment times or some unobserved characteristics for the particular set of stations. Similar regressions that estimate employment density separately for the Red and Gold Lines, and by geographic submarket, yield no significant results on *Post*Station*, even among the oldest station clusters in Central Los Angeles and North Hollywood (results available from authors upon request).[13]

[13] These regressions were estimated for Central Los Angeles, North Hollywood, Arroyo Seco, and Pasadena submarkets. Only one station in downtown Los Angeles opened after 1996, so we exclude the DTLA cluster.

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 5- and 10-year windows after station opening (exhibit 13). The coefficients from 3 years before to 5 years after opening (columns 1 to 4) show similar results to the difference-in-means tests shown in exhibit 11. During the immediate 5-year period after station opening, employment in station areas shifted toward 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 near stations, including medical facilities and schools, had relatively smaller employment losses during the Great Recession than private sector firms. These results also may indicate greater public investment around stations; for example, new buildings for the California Transportation Department and the Los Angeles Police Department were constructed around the Civic Center station after station opening.

Exhibit 13

Employment Density, by Industry Category

Dependent Variable	Percent of Employees in Industry Category							
Time Window	t-3 to t+5				t-5 to t+10			
Industry Category	Commercial	Public/ Institution	Industrial	Miscellaneous	Commercial	Public/ Institution	Industrial	Miscellaneous
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Station	5.56	– 1.62	– 2.84	– 1.10	8.324*	– 4.09	– 3.06	– 1.18
	(4.85)	(5.71)	(3.55)	(1.93)	(4.65)	(5.44)	(3.37)	(1.69)
YrsPre	0.86	– 1.94	0.74	0.35	0.49	– 2.03	1.32	0.22
	(1.57)	(1.58)	(1.10)	(0.85)	(1.57)	(1.57)	(1.02)	(0.85)
Station*YrsPre	0.26	– 0.37	0.17	– 0.06	– 0.50	0.60	– 0.15	0.05
	(0.50)	(0.58)	(0.47)	(0.28)	(0.41)	(0.48)	(0.40)	(0.20)
YrsPost	– 0.90	1.37	– 0.05	– 0.42	– 0.65	0.96	0.04	– 0.35
	(1.53)	(1.56)	(1.09)	(1.21)	(1.57)	(1.62)	(0.98)	(0.85)
Station*YrsPost	0.66	0.07	– 0.55	– 0.04	– 0.61	1.171**	– 0.49	– 0.07
	(0.59)	(0.54)	(0.49)	(0.33)	(0.44)	(0.57)	(0.38)	(0.21)
Observations	558	558	558	558	872	872	872	872
R-squared	0.237	0.158	0.129	0.111	0.226	0.154	0.122	0.118

*** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Notes: 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.

Conclusions and Policy Implications

The Los Angeles metropolitan area is one of several U.S. regions that have recently made substantial public investments in subway or light rail systems. 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. In this article, we examine how employment patterns have changed around newly opened rail stations in Los Angeles during the last two decades. Although this study focuses on Los Angeles, the results are likely to be relevant to transit planners who are building or expanding rail networks (including streetcars) in cities with similar urban environments, particularly with low transit ridership, multiple employment subcenters, and a densely built urban core.

Results indicate that employment densities in station and control areas fluctuated somewhat over time with regional economic cycles, but there are few clear time trends among study areas. Station areas did not see stronger employment growth within the first 5 years after station opening, but a small group of stations that opened between 1996 and 1999 saw significant employment gains between 5 and 10 years after stations opened.

The relatively scattershot and delayed employment gains near stations most likely reflect two features of the LA Metro system. First, rail transit ridership in Los Angeles is quite low, relative to other large U.S. cities. Due to complicated political considerations that drove the route planning—and perhaps the need to avoid established residential neighbors who opposed the rail—Los Angeles's rail stations were located in areas with high initial job density, although the system did not create direct connections to important job centers on the city's west side. The polycentric employment structure in the Los Angeles metropolitan area makes it difficult for most households to complete the home-to-work journey entirely by rail, therefore it is unclear that most rail stations increase neighborhood accessibility and will result in higher land values. The employment gains around Red and Purple Line stations 5 to 10 years after opening also coincides roughly with the opening of the Gold Line. It is possible that proximity to the older stations became more valuable once the Metro system expanded.

Second, 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. Relative to the legacy systems in New York City and Boston, or even systems like Washington, D.C.'s Metro and San Francisco's BART, LA Metro stations may be too new for land use patterns to have adjusted. The example of the Hollywood and Vine station suggests that, even in areas with strong market demand and TOD-friendly zoning, it may take a decade or more for changes to land use patterns and physical development to emerge.

One potentially important factor our study cannot address is the role of zoning or other localized policy interventions in facilitating development around stations. A parallel qualitative study reveals that the type and density of buildings allowed under zoning varies substantially across sample stations (Schuetz, Giuliano, and Shin, 2017). High-density residential and commercial uses consistent with TOD are allowed near all stations in downtown Pasadena and some parts of downtown and central Los Angeles, but many stations have complex or ambiguous zoning that may hinder redevelopment. Los Angeles and Pasadena also demonstrate fundamentally different approaches to land use planning near transit stations. Pasadena adopted new, density-friendly zoning around all its downtown station areas around the time that Gold Line service began. By contrast, Los Angeles has conducted only piecemeal rezoning or granted variances around selected stations, and those changes were not always implemented when stations opened. More recently, LA Metro 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.[14] This offers one alternative way to coordinate zoning and infrastructure development across multiple agencies; evaluating its effectiveness will be an interesting area for future research.

The experience of Los Angeles offers two key lessons for policymakers in other regions. First, even if rail networks generate long-run economic spillovers to surrounding areas, short-run impacts may be quite limited, especially in regions without strong public transportation usage. Second, transit infrastructure may be intended to serve multiple goals, each of which implies different strategies for station location, coordinating policies, and metrics of success. For instance, if the primary goal is to facilitate access of workers to existing jobs, then stations should be located near large employment centers and near dense residential areas with high proportions of workers who commute to those employment centers. However, residential and commercial areas with high prior density may offer less potential (or require more time) for additional development. If the primary goal is to encourage more or denser residential development, then placing stations in greenfields areas and revising the nearby zoning to allow dense mixed-use development may be a more effective location strategy. Realistically, however, Los Angeles' example suggests that political feasibility may be at least as important as economic efficiency in driving both station placement and coordinating land use policies.

Appendix

Exhibit A-1

Industry Categories, by Two-Digit NAICS Code

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
	Administrative and support and waste management and remediation	56
Public/Administrative		
	Educational services	61
	Health care and social assistance	62
	Public administration	92
Miscellaneous		
	Agriculture, forestry, fishing and hunting	11
	Other services	81

NAICS = North American Industry Classification System.

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

Acknowledgments

This research was supported by a grant from the John Randolph and Dora Haynes Foundation. The analysis and conclusions set forth are solely the responsibility of the authors. The authors benefited from thoughtful comments from Steve Billings, Ed Coulson, Mark Shroder, participants at the Lincoln Institute for Land Policy's Urban Economics and Public Finance Meetings, and several anonymous reviewers.

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