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Effects of Urban Rail Transit Expansions: Evidence from Sixteen Cities, 1970–2000

FEDERAL, STATE, AND LOCAL governments have spent more than $25 billion to establish or expand rail transit infrastructure in sixteen major U.S. metropolitan areas between 1970 and 2000. Billions more have been invested to maintain and improve existing rail transit lines. Despite the significant infrastructure improvements associated with these investments, transit ridership has been declining rapidly. The fraction of metropolitan area commuters in the United States using public transit declined from 0.12 in 1970 to 0.06 in 2000. Furthermore, only in a few metropolitan areas has transit increased its share of the commuting market since 1970, and in none of these areas did transit garner more than 10 percent of the market in 2000.

In this paper, we evaluate the extent to which rail transit improvements have spurred new ridership and we provide some rough estimates of the value of these new commuting options. We demonstrate the importance of considering heterogeneous responses of commuting mode choice both within and between metropolitan areas to the existence of new rail lines. For example, in each metropolitan area except Chicago, commuters living beyond ten kilometers of the city center and within two kilometers of a new rail transit line increased their transit use between 1970 and 2000. However, most metropolitan areas saw declines in ridership within ten kilometers of the city center in areas near and far from new rail lines alike. Variation in metropolitan area

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structure is also key in determining whether new rail lines succeed at attracting riders. Rail transit is more likely to be successful in more densely populated and centralized cities. Of the sixteen cities that significantly expanded their rail infrastructure after 1970, we find that Washington stands out as a place where rail transit investments have had relatively high returns. Finally, we find little evidence that significant ridership gains due to new rail lines continue to accrue more than a few years after construction is completed.

Panel data at the census tract level allow us to evaluate the effects on ridership of new rail lines by making two types of comparisons. Exploitation of within metropolitan area variation in access allows for comparison of areas of each city that received new rail transit to equivalent areas that did not. Time series variation in transit access allows for comparison of the same census tract in each city over time. This difference-in-difference type comparison ultimately identifies our estimates of ridership gains as a result of new rail transit. Census data on commuting times and the number of rail, bus, and car commuters allow us to roughly calculate the number of commuting hours saved as a result of new rail transit construction.

We develop a simple theoretical model that provides intuition about the spatial patterns in commuting mode choice adjustments that one may expect to see as result of new rail transit infrastructure. The implications of the model motivate the specifications used in public transit use regressions. These regressions incorporate potentially heterogeneous responses of public transit use to new rail infrastructure as a function of the year the system was built, distance to the city center, and physical structure of the metropolitan area as a whole. These regressions form the core empirical contribution of this paper. We use the regression estimates to evaluate the extent to which new rail transit causes people to change commuting modes, allowing us to roughly quantify the welfare benefits of recently constructed rail lines and to make some predictions about the likely success or failure of rail transit construction projects currently underway in several U.S. cities.

Our study builds on earlier research investigating the consequences of rail transit investments. In a previous paper, we document that transit ridership saw less than average declines near new rail lines constructed in five U.S. cities during the 1980s.[1] On the other hand, metropolitan areas have been decentralizing such that existing transit infrastructure facilitates access to a smaller fraction of residents and employment.[2] This is reflected in falling

1. Baum-Snow and Kahn (2000).
2. Glaeser and Kahn (2001).

transit ridership in areas around rail transit lines that existed in 1970. Another study examines in detail the case of Atlanta and demonstrates that given the current spatial distribution of residences and employment, an enormous investment in transit would have to occur to have any hope of garnering a large share of the commuting market, let alone a significant share of the market for other types of trips.[3] Rather than examine one city in detail, our paper systematically investigates public transit use in each of the sixteen cities with major rail transit infrastructure improvements between 1970 and 2000. Variation in the structure of these metropolitan areas facilitates evaluation of the role urban form plays in determining the distribution of commuting mode choice responses to new rail transit infrastructure across different cities.

Changes in Transit Ridership and Access, 1970–2000

Across the United States, fewer people are commuting by public transit now than in the recent past. We document wide variation across different metropolitan areas in transit ridership trends and rail transit infrastructure improvements. We demonstrate that population decentralization accounts for an important part of the decline in transit use. Further, we show that in many cities a large fraction of the population still does not live near a rail line despite large infrastructure improvements.

Data

Demographic data at the census tract level and digital maps of rail transit infrastructure at various times together form the core data set used for this analysis. The census tract data, which is from the Urban Institute and Census Geolytics' Neighborhood Change Database, is a set of repeated cross sections from the 1970, 1980, 1990, and 2000 decennial censuses normalized to 2000 census tract geography. These data contain the evolution of demographic characteristics and transit ridership for the same geographic areas over time. Census tracts are sufficiently small to facilitate a detailed analysis of trends in commuting mode choice and travel time as a function of location. We use geodata from the Neighborhood Change Database to map the locations of census tract centroids.

The Bureau of Transportation Statistics' National Transportation Atlas Database (NTAD) forms the basis of the rail transit spatial data. NTAD

3. Bertaud (2003).

includes digital maps of rail transit lines and stations for most U.S. cities. In the areas for which NTAD data are not available or up-to-date, we constructed digital maps of lines and stations based on digital street maps and physical maps of transit lines' locations to reflect infrastructure as of January 1, 2004. We use transit construction histories from various sources to form digital maps of the transit infrastructure and stations on January 1, 1970, 1980, 1990, 1994, and 2000, in addition to 2004.[4] We only include modern rapid transit lines, not vintage trolleys or commuter rail lines. The full set of transit lines in the data set is detailed in table 1, which highlights differences across cities with respect to the timing and extent of rail transit construction. For example, the majority of San Francisco's rail transit system was built in the early 1970s, with a few expansions in the 1990s. In contrast, Washington saw new rail transit construction more or less continuously throughout the 1970s, 1980s, and 1990s. Table 1 also demonstrates the existence of huge nominal construction cost differences across cities.

Central Business District (CBD) definitions are taken from the 1982 Economic Censuses Geographic Reference Manual. They represent agglomerations of census tracts that surveyed local business leaders reported to represent the center of economic activity for each metropolitan region. Visual inspection reveals that these CBDs match closely with general perceptions of the location of downtown.

In most of the analysis, our sample includes only census tracts with centroids that fall within twenty-five miles of the nearest CBD of a metropolitan area that had rail transit expansions between 1970 and 2000.

Ridership Trends

Table 2 presents trends in the market share of public transit in commuting between 1970 and 2000. It demonstrates the existence of large, aggregate declines in the fraction of commuters using public transit. Across all metropolitan areas, the fraction of commuters using public transit fell from 12 percent in 1970 to just 6 percent in 2000. These declines have occurred in metropolitan areas with historically high transit use and significant rail infrastructure in 1970 (old-transit cities), metropolitan areas that established significant rail transit infrastructure since 1970 (new-transit cities), and metropolitan areas without rail transit in 2000 (no-transit cities). Though in percentage terms rail transit cities saw less rapid declines in use than cities with no rail transit, transit lost more market share in cities with rail lines. In cities with rail transit in

4. These sources are available upon request from the authors.

Table 1. Rail Transit Construction in the United States, 1970–2004[a]

City	*Line*	*Length (miles)*	*Open by*	*Estimated cost per mile (millions of current dollars)*	*Type of Construction[b]*
Atlanta	East/West	14	1979	33	R/T/E
	North/South	2	Dec 1981	33	T
	North/South	2	Sep 1982	33	T
	North/South	9	Dec 1984	33	T
	North/South	2	Aug 1986	33	R
	North/South	3	Dec 1987	33	R
	North/South	3	Jun 1988	33	R
	East/West	1	Dec 1992	33	E
	North/South	2	Dec 1992	33	R
	East/West	3	Jun 1993	33	R
	North/South	7	Jun 1996	52	H
	North/South	2	Dec 2000	33	E
Baltimore	Metro Subway	8	1983	100	T/E
	Metro Subway	6	1987	?	H
	Metro Subway	2	1994	?	T
	Light Rail	23	1993	18	S/H/R
	Light Rail	8	1997	14	R/N
Boston	Orange Line	3	1975	?	E[c]
	Orange Line	5	1975	?	R
	Orange Line	1	1977	?	R
	Red Line	6	Sep 1971	?	R
	Red Line	3	Mar 1980	?	R
	Red Line	3	Mar 1985	179	T
	Orange Line	4	May 1987	?	E[c]
	Orange Line	5	May 1987	158	R
	Green Line	2	1985	?	S[c]
Buffalo	Metro Rail	6	1984	103	S/T
Chicago	Blue Line	5	Feb 1970	10	S/H
	Blue Line	6	1984	?	H
	Orange Line	9	1993	56	R
	Green Line	1	1994	?	E[c]
Dallas	DART	20	May 1997	43	S/R/T
	DART	13	Dec 2002	43	R/H
Denver	D	6	Oct 1994	21	S
	C/D	9	July 2000	22	S
	C	2	April 2002	24	R
Los Angeles	Red Line	4	Jan 1993	330	T
	Red Line	7	July 1996	245	T
	Red Line	12	2000	227	T

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Table 1. Rail Transit Construction in the United States, 1970–2004[a] (continued)

City	*Line*	*Length (miles)*	*Open by*	*Estimated cost per mile (millions of current dollars)*	*Type of Construction[b]*
	Blue Line	22	1990	40	R
	Green Line	20	1995	36	H/E
	Gold Line	14	July 2003	63	R
Miami	Metrorail	21	1985	48	R/E
	Metrorail	2	May 2003	?	E
Portland	MAX	15	1986	14	R/S
	MAX	18	Sep 1998	54	S/T/H
	MAX	6	Jul? 2001	23	E/H
	MAX	6	May 2004	63	S
Sacramento	North/East Line	18	1987	10	S/H/R
	East Line	2	Jan 1998	15	S/R
	South Line	6	Dec 2003	35	R
	East Line	3	June 2004	32	S/R
San Diego	Blue Line	16	July 1981	8	R/S
	Orange Line	4	March 1986	7	R
	Orange Line	11	1989	10	R
	Orange Line	2	1990	32	R
	Blue Line	1	1992	?	R
	Blue Line	4	1996	37	R
	Blue Line	6	1997	37	E
	Orange Line	4	Sep 1998	30	S
San Francisco	BART	28	Sep 1972	16	T/E/R
	BART	12	Jan 1973	16	T/R
	BART	17	May 1973	16	H/R
	BART	8	Nov 1973	16	T
	BART	2	Feb 1996	106	T
	BART	7	Dec 1996	?	?
	BART	6	May 1997	?	H
	BART	10	June 2003	106	T
	MUNI	2	1998	37	S
San Jose	VTA	6	June 1988	25	S
	VTA	2	Aug 1990	25	H
	VTA	11	April 1991	25	H
	VTA	8	Dec 1999	42	S
	VTA	2	May 2001	39	S/E
	VTA	6	June 2004	54	S
St. Louis	MetroLink	16	July 1993	27	R
	MetroLink	1	June 1995	27	E
	MetroLink	17	May 2001	20	?
	MetroLink	4	Jun 2003	?	?

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Table 1. Rail Transit Construction in the United States, 1970–2004[a] (continued)

City	*Line*	*Length (miles)*	*Open by*	*Estimated cost per mile (millions of current dollars)*	*Type of Construction[b]*
Washington	Red Line	6	Jan 1977	?	T/E
	Blue Line	12	July 1977	82	T/H
	Red Line	6	Feb 1978	?	R
	Orange Line	7	Nov 1978	?	R
	Orange Line	3	Dec 1979	106	T
	Blue Line	4	Nov 1980	?	T
	Red Line	2	Dec 1981	?	T
	Yellow Line	3	Apr 1983	?	T
	Blue Line	4	Dec 1983	?	R
	Red Line	14	1984	?	R
	Orange Line	9	Jun 1986	26	H
	Red Line	3	Sep 1990	?	T
	Green Line	2	May 1991	?	T
	Blue Line	4	Jun 1991	?	R
	Green Line	3	Dec 1991	?	T
	Green Line	7	Dec 1993	?	R
	Blue Line	3	Jun 1997	53	R
	Red Line	1	Jul 1998	162	T
	Green Line	3	Sep 1999	222	T
	Green Line	7	Jan 2001	138	T/H/E

a. Data come from a variety of sources that are available upon request from the authors. Documentation of construction costs or alignment type for all segments was not available. A few short rail segments in Cleveland and New York City are excluded from this table, as is a rail line opened in 1999 in Salt Lake City. ? = unavailable or unknown.

b. Construction types codes are as follows: R = Railway Right of Way, T = Tunnel, S = Street, H = Highway Median, and E = Elevated.

c. Section was closed by the given date.

1970, 30 percent commuted by public transit in 1970, declining to just 23 percent by 1990. In new-transit cities, the fraction dropped from 8 to 6 percent in the same period, and in no-transit cities the fraction dropped from 5 to 2 percent. Transit use in all three samples remained relatively unchanged between 1990 and 2000, with the steepest declines occurring in the 1970s in old-transit and no-transit cities, and in the 1980s in new-transit cities.

The final column in table 2 reports public transit commute shares in 2000 weighted by the spatial distribution of the population in 1970.[5] Therefore, it gives a sense of the decline in transit use due to mode switching relative to

5. The weighted average is calculated as $\Sigma(T_i^{00}C_i^{70}/C_i^{00}) / \Sigma(C_i^{70})$, where T_i^Y and C_i^Y are the total number transit users and commuters, respectively, in tract i and year Y. A similar exercise weighting the fraction of 1970 commuters using transit by the number of commuters in 2000 yields numbers that are below the 1970 fractions listed in table 2 in every case.

Table 2. Trends in Usage: Fraction of Workers Outside the Home Commuting by Public Transit, 1970–2000[a]

	1970	*1980*	*1990*	*2000*	*2000[b]*
MSAs with rail transit in 1970					
Boston	0.18	0.14	0.14	0.15	0.16
Chicago	0.26	0.21	0.19	0.17	0.19
Cleveland	0.13	0.10	0.06	0.05	0.07
New York	0.45	0.37	0.37	0.38	0.39
Philadelphia	0.23	0.16	0.13	0.11	0.16
Pittsburgh	0.16	0.13	0.09	0.08	0.11
San Francisco	0.18	0.19	0.17	0.17	0.18
Total	**0.30**	**0.25**	**0.23**	**0.23**	**0.25**
MSAs with no transit in 1970 that constructed rail transit between 1970 and 2000					
Atlanta	0.09	0.09	0.06	0.05	0.11
Baltimore	0.15	0.11	0.09	0.07	0.12
Buffalo	0.11	0.07	0.05	0.04	0.06
Dallas	0.06	0.04	0.03	0.02	0.05
Denver	0.05	0.06	0.05	0.05	0.07
Los Angeles	0.05	0.07	0.07	0.07	0.07
Miami	0.08	0.06	0.05	0.05	0.08
Portland	0.06	0.09	0.06	0.07	0.09
Sacramento	0.02	0.04	0.03	0.03	0.04
Salt Lake City	0.02	0.05	0.03	0.03	0.04
San Diego	0.04	0.04	0.04	0.04	0.05
San Jose	0.03	0.04	0.03	0.04	0.04
St. Louis	0.09	0.06	0.03	0.03	0.06
Washington	0.17	0.16	0.16	0.14	0.20
Total	**0.08**	**0.08**	**0.06**	**0.06**	**0.09**
MSAs with no rail transit in 2000	**0.05**	**0.03**	**0.02**	**0.02**	**0.04**
All MSAs	**0.12**	**0.08**	**0.07**	**0.06**	**0.10**

Source: Authors' calculations.

a. Each entry is calculated using all 2000-definition census tracts in the given category with valid data. MSAs (metropolitan statistical areas) are defined as all tracts within twenty-five miles of the CBD. Results are within .01 for "other MSAs" and "all MSAs" if standard MSA definitions are used instead. See table 1 for details on rail expansion by city.

b. Counterfactual fraction of people that would have commuted by transit in 2000 were the population at its 1970 spatial distribution. The formula is sum(Ti00Ci70/Ci00)/sum(Ci70) where Ti^Y and Ci^Y are the total number transit users and commuters respectively in tract i and year Y. A similar exercise weighting the fraction of 1970 commuters using transit by the number of commuters in 2000 yields numbers that are below the 1970 fractions listed in this table in every case.

that due to changes in the spatial distribution of the population away from transit-accessible areas. This column shows that in each of the metropolitan areas with rail transit infrastructure in 2000, transit use would be higher were the population still at its 1970 spatial distribution. We predict that public transit's share of commuters in all metropolitan areas would be 4 percentage points higher in 2000 had the population not suburbanized since 1970.

Among old-transit cities, only in San Francisco did public transit use remain relatively steady between 1970 and 2000. The city saw by far the greatest increase in rail transit infrastructure over this period. Among others in this category, only Boston and New York saw their transit use stabilize after 1980. In Boston, the quality of service on the rail system has improved considerably since 1980 and two major extensions of the city's Red Line opened. New York's robust population growth in central areas during the 1980s and 1990s, reversing the sharp decline in the 1970s, and marked improvement in the quality of the city's transit services may account for its rebound in transit use. In Philadelphia, Pittsburgh, and Cleveland, three old-transit cities with little or no change in rail infrastructure between 1970 and 2000, public transit use has fallen precipitously. Chicago also saw a large decline in transit use despite several important improvements in rail transit infrastructure. Overall, New York remains the metro area with the greatest share of public transit riders, declining from 45 percent in 1970 to 37 percent in 1980 and 38 percent in 2000. The final column of table 2 shows that in each of the old-transit cities except San Francisco, more than half of the decline in aggregate transit use can be attributed to mode switching.[6]

Transit use in the new-transit cities saw much less steep declines overall, from 8 percent of commuters using transit in 1970 to 6 percent in 2000. Among these cities, the steepest declines in transit use occurred in Baltimore, Buffalo, and St. Louis, all metropolitan areas with rapidly declining population and employment in their center cities. Denver, Los Angeles, Portland, Sacramento, Salt Lake City, and San Jose experienced small increases in public transit use between 1970 and 2000, though all started from a market share of less than 7 percent in 1970. Each of these metropolitan areas had stable or increasing center-city populations. The remaining new-transit cities, Atlanta, Dallas, Miami, and Washington, have experienced small to medium declines in usage. The final column shows that new rail transit construction may have been successful at drawing new riders to transit in some new-transit cities. Holding the population at its 1970 spatial distribution, nine of the fourteen new-transit cities experienced increased transit use between 1970 and 2000.

Trends in Access

Table 3 documents trends in rail transit access by city. The table presents the fraction of land area within two kilometers of a rail transit line and fraction of commuters living within two kilometers of a transit line for each census

6. In 1970, 17.6 percent of commuters in the San Francisco area used transit compared to 17.1 percent in 2000. Weighted by the number of commuters in 1970, transit's share in 2000 was 18.0 percent.

Table 3. Trends in Access: Fraction of Land Area and Fraction of Workers Outside the Home within Two Kilometers of Rail Transit, 1970–2000[a]

	1970	*1980*	*1990*	*2000*	*Total tracts*
Fraction within two kilometers of rail transit					
Atlanta					
Land area	0.00	0.01	0.04	0.05	512
Workers outside the home	0.00	0.07	0.11	0.13	
Baltimore					
Land area	0.00	0.00	0.02	0.07	571
Workers outside the home	0.00	0.00	0.12	0.19	
Boston					
Land area	0.05	0.06	0.07	0.07	717
Workers outside the home	0.28	0.28	0.33	0.32	
Buffalo					
Land area	0.00	0.00	0.01	0.01	289
Workers outside the home	0.00	0.00	0.12	0.11	
Chicago					
Land area	0.12	0.13	0.15	0.17	1,449
Workers outside the home	0.40	0.35	0.36	0.39	
Dallas					
Land area	0.00	0.00	0.00	0.03	723
Workers outside the home	0.00	0.00	0.00	0.08	
Denver					
Land area	0.00	0.00	0.00	0.01	547
Workers outside the home	0.00	0.00	0.00	0.05	
Los Angeles					
Land area	0.00	0.00	0.00	0.07	2,022
Workers outside the home	0.00	0.00	0.00	0.15	
Miami					
Land area	0.00	0.00	0.07	0.07	448
Workers outside the home	0.00	0.00	0.15	0.12	
Portland					
Land area	0.00	0.00	0.02	0.05	393
Workers outside the home	0.00	0.00	0.16	0.23	
Sacramento					
Land area	0.00	0.00	0.03	0.03	348
Workers outside the home	0.00	0.00	0.15	0.15	
San Diego					
Land area	0.00	0.00	0.07	0.10	467
Workers outside the home	0.00	0.00	0.19	0.28	
San Francisco					
Land area	0.04	0.18	0.18	0.19	719
Workers outside the home	0.24	0.48	0.48	0.51	

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Table 3. Trends in Access: Fraction of Land Area and Fraction of Workers Outside the Home within Two Kilometers of Rail Transit, 1970–2000[a] (continued)

	1970	*1980*	*1990*	*2000*	*Total tracts*
San Jose[b]					
Land area	0.00	0.01	0.02	0.05	472
Workers outside the home	0.00	0.03	0.07	0.21	
St. Louis					
Land area	0.00	0.00	0.00	0.02	440
Workers outside the home	0.00	0.00	0.00	0.06	
Washington					
Land area	0.00	0.04	0.09	0.12	845
Workers outside the home	0.00	0.20	0.28	0.33	

Source: Authors' calculations.

a. Sample includes all census tracts within twenty-five miles of each central business district.

b. Some tracts attributed to San Jose were within two kilometers of Bay Area Rapid Transit (BART) lines that connect to San Francisco.

year between 1970 and 2000 in each city with rail transit expansions during that period. Cases in which the latter share is falling and former is constant reflect falling population density in rail accessible areas relative to other areas. There is considerable heterogeneity in the scope of rail transit expansions across cities. Portland, San Diego, San Francisco, San Jose, and Washington experienced increases of more than 20 percentage points in the fraction of commuters living within two kilometers of rail transit while other cities saw much smaller increases. Table 3 demonstrates that the number of additional commuters served on the margin decreased with new rail transit construction. That is, rail transit infrastructure in 1970 served a larger commuter population per percentage of land area covered than subsequent expansions. Furthermore, new-transit cities have generally required more rail transit construction to reach a given fraction of commuters than old-transit cities. For example, rail transit in Boston served only 7 percent of the land area but 32 percent of commuters in 2000. In contrast, rail transit in Los Angeles also served 7 percent of the land area but only 15 percent of commuters.[7] In 2000 at least one-quarter of commuters lived within two kilometers of rail transit in only Boston, Chicago, New York, Philadelphia, San Diego, San Francisco, and Washington.

Ideally, we would like to evaluate the effects of new rail lines holding all other transit service constant. It is common, however, for transit authorities

7. On the margin, Boston and Los Angeles have had similar fractions of commuters served by rail transit construction between 1970 and 2000. Each gained about 2 percentage points of commuters for each extra percentage point of land area covered.

to reorient their bus networks to serve new rail transit lines at the expense of more direct downtown service or for bus service to be reduced or eliminated on routes that are close substitutes to the rail lines. While detailed historical geodata on bus routes are not readily available, an analysis of recent trends implies that this is unlikely to be a major concern. We have examined the evolution of maximum buses in service for each rail transit metropolitan area. We find that bus service has been increasing over time in most cities. Much of this is likely to be driven by the need for buses to serve the increasing sprawl of suburbia.

Theory

We develop a simple model in order to fix ideas about the types of responses one might expect to see in the data to new rail transit infrastructure. The primary lesson from the model is that most mode switchers from car to rail are likely to live far from the city center. The number of mode switchers from driving will depend heavily on the travel speed on the rail line relative to driving. Moreover, while some new rail commuters will switch from driving, most are likely to be former bus users. The model highlights that rising wages and the associated higher value of time makes it even more critical that rail lines be fast in order to capture a significant share of the commuting market.

The model is based on the standard monocentric city framework of Alonso and Muth.[8] This formulation of their model is largely inspired by LeRoy and Sonstelie's observations about how it would generalize to allow for multiple commuting modes with different fixed and marginal costs.[9] It also includes elements of Baum-Snow's model in which at a given distance from the CBD, there exist heterogeneous commuting times to the CBD.[10] Since such a small fraction of those working outside CBDs commute by public transit, we view the monocentric model as a reasonable simplification of reality that holds the considerable advantage of facilitating straightforward comparison of equilibrium commuting mode choices made in different parts of metropolitan areas.[11]

8. Alonso (1964) and Muth (1969).
9. LeRoy and Sonstelie (1983).
10. Baum-Snow (2005).
11. Data from the 1990 census show that the vast majority of people at risk of commuting by public transit worked in the CBD. Commuters who worked in the same Public Use Micro Data Area as the CBD in 1990 were much more likely to use public transit than commuters who lived and worked in the suburbs. In the sixteen metropolitan areas that experienced rail transit

Model

Each metropolitan area has a continuum of identical individuals who distribute themselves over the available space such that in equilibrium everyone has the same level of utility. Each individual has preferences over space s and a composite consumption good z, and is endowed with one unit of time that can be used only for working to earn wage w or commuting. All work takes place in the CBD. Space is indexed in polar coordinates (r,ϕ) such that r equals 0 at the CBD and ϕ is the angle to the nearest transit line. Commuters can drive and ride the bus along any ray from the origin or any line perpendicular to a rail line at speeds $1/b_D$ and $1/b_B$, with $b_B>b_D$. Rail lines emanate as linear rays from the CBD only conveniently serving certain areas of the city. The speed of travel along rail lines is $1/b_R$, with $b_R<b_B$. We make no assumptions for now about the relative speeds of driving and rail because in the data different metropolitan areas have different orderings. There is a fixed pecuniary cost to owning a car, which we denote as C. We normalize the fixed pecuniary cost of taking transit to 0. Transit has a fixed time cost of X. There is no fixed time cost of driving.

Those who use the rail line for part of their commute have the options of traveling to the rail line using either the bus or car. Thus everyone has four commuting options: taking a bus to the rail line (R_B), driving to the rail line (R_D), taking a bus directly downtown (B), or driving directly downtown (D). Transit users only incur their fixed cost X once, even if they transfer between bus and rail.[12] Each commuter chooses the minimum cost option such that the total commuting cost for a commuter living at location (r,ϕ) earning wage w is:

$$\min\left[C + wb_D r, w\left(X + b_B r\right), w\left(X + b_B r\sin\phi + b_R r\cos\phi\right),\right.$$
$$\left. C + w\left(X + b_D r\sin\phi + b_R r\cos\phi\right)\right].$$

expansions between 1970 and 2000, 13 percent of center-city workers commuted to work by public transit while only 3 percent of suburban workers commuted to work by public transit. Of center-city residents who worked in the Central Business District, 15 percent used transit, while 10 percent of suburban residents working in the Central Business District used transit in 1990. Only in Washington and San Francisco did more than 10 percent of center-city dwellers that did not work in the CBD commute by public transit. We cite data from the 1990 census instead of the 2000 census because geography defining place of work is more spatially disaggregated in the 1990 census.

12. It is perhaps more intuitive to also give the option of walking to the nearest rail line. Because walking is slower than taking the bus, nobody is on the margin between driving and walking. We choose not to introduce walking in order to keep notation and the number of parameters to a minimum. Qualitative implications of the model are not sensitive to this simplification.

Assuming that rail transit is not so widespread in the city that it is optimal for nobody to use mode B, there is some angle ϕ_B at which commuters are indifferent between modes B and R_B, and functions that define indifference between modes D and R_D, B and D, and R_B and R_D. These functions allow us to break up the city into the regions in which each commuting mode is used. We now consider the mode choice of people in each region as a function of the wage in the city and how this choice changes when a new rail line is introduced.

We can analyze mode choice by evaluating bid-rent curves for land as a function of distance from the CBD. The bid-rent is the maximum an individual would be willing to pay for a unit of space given a particular commuting option and residential location. It is derived by solving for the rental rate of land from an individual's budget constraint. The commuting option that prevails is determined by the highest bid-rent conditional on commuting mode and location. Denote the bid-rent function for mode M as ψ^M. In a region sufficiently far from a rail line, the market rent function is given by the upper envelope of the bid-rent functions for driving and taking the bus:

$$\psi(r,u;w) = \max\left\{\max_s\left[\frac{\mathrm{w}(1-\mathrm{b_D r}) - \mathrm{C} - Z(s,u)}{s}\right],\right. \left.\max_s\left[\frac{w(1-X-\mathrm{b_B}r) - Z(s,u)}{s}\right]\right\}.$$

Using the Envelope Theorem, it is straightforward to see that the slope of the bid-rent function with respect to r, conditional on taking the bus, is steeper than the slope conditional on driving. This result comes from the fact that the marginal cost from the lost work time of riding the bus is greater than that of driving due to the slower bus speed. If the wage is sufficiently low, the high fixed pecuniary cost C dominates the mode choice decision, leading everyone to take the bus. Conversely, if the wage is sufficiently high, the fixed time cost X dominates the mode choice decision, leading everyone to drive. For some intermediate range, however, the mode choice depends on distance r. Those living closer to the center ride the bus while those living further from the center drive.

The same logic applies in the region near a rail line, the only difference being the commuting technology and the fact that mode choice is a function of both the angle ϕ and the CBD distance r. Consider the case of people living on top of the rail line, or where $\phi = 0$. If driving is faster than rail (case 1), the same pattern as in the bus region ensues with the mode-switching distance further in the rail region than the bus region. In this case, it is not optimal for anybody in the city to choose mode R_D because the rail speed cannot make up for the fixed costs of both modes that are incurred. Mathematically, $\psi^{RD}(0,0) < \psi^{D}(0,0)$ and $\psi_r^{RD}(r,\phi) < \psi_r^{D}(r,\phi)$ for all ϕ in $(0,\pi/2)$ implying that $\psi^{RD} < \psi^{D}$ everywhere. If rail is faster than driving, some former bus users find it optimal to ride the bus (or walk) to the rail line instead of taking the bus directly downtown, as in case 1. Others will get rid of their cars and take the bus (or walk) to the rail line instead of driving to work. This group of people is larger than in case 1. Another group of people will drive to the rail station instead of driving directly downtown. These people will exclusively live far from the CBD.

Figure 1 graphically displays bid-rents as a function of r and mode choice. The bid-rent function conditional on modes R_B and R_D are shown only for those living at $\phi=0$. As ϕ increases, ψ^{RB} gets steeper such that $\psi^{RB}(r,\phi_B) = \psi^{B}(r,\phi_B)$. ψ^{RD} also gets steeper as ϕ increases, though at a slower rate than ψ^{RB} such that for all $\phi > 0$, $\psi^{RD}(r,\phi) > \psi^{RB}(r,\phi)$ if r is sufficiently large. In figure 1, r_B is the distance at which agents are indifferent between driving and taking the bus. Assuming case 1, $r_{RD}(0)$ is the distance at which agents living on the rail line are indifferent between driving and taking the rail line. As discussed above, $r_{RD}(0) > r_B$.

We derive qualitative implications of the spatial distribution of commuting mode choice by solving for functions of r and ϕ that set costs for two travel modes equal. These functions define indifference lines between commuting modes. We denote indifference lines between modes B and R_B, or D and R_D, as ϕ_B and $\phi_D(r)$, respectively. It is straightforward to show that the indifference lines between modes R_B and R_D are parallel to the rail line. The indifference lines between modes R_B and D are decreasing in ϕ for small ϕ if $b_R > b_D$[13].

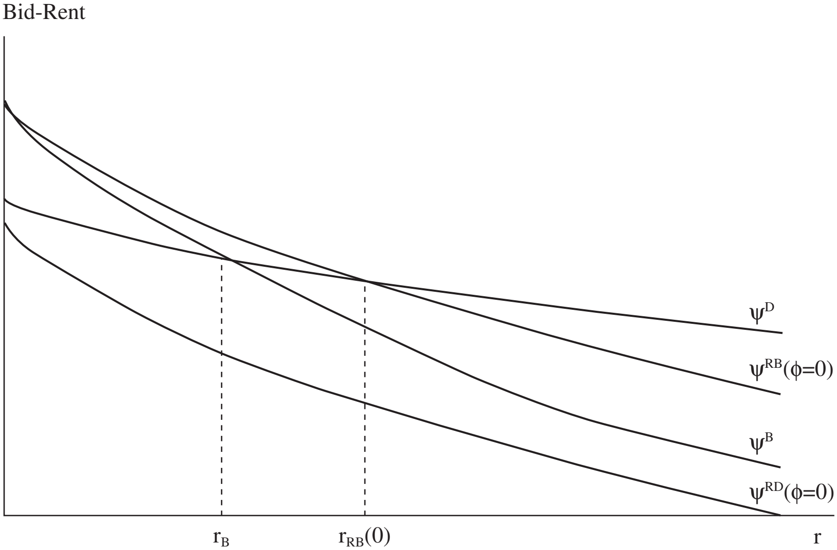
Figure 2 depicts commuting mode choices in a metropolitan area given the assumptions of case 1 and case 2. When a new rail line is introduced, it induces all bus users within angle ϕ_B of the rail line to switch to commuting by rail. Further, it induces a segment of the population living within angle ϕ_B at $r>r_B$ to switch from mode D to mode R_B[14]. These mode switchers are the people who were near the margin between using the bus and driving before the new rail line appeared. The equilibrium with a rail line features a higher

13. To see these relationships, note that the indifference relationship between R_B and R_D is given by $r^*\sin\phi = (w/(C(b_B-b_D)))$, and the relationship between R_B and D is given by $r = (C/w-X)/(b_B\sin\phi+b_R\cos\phi-b_D)$.

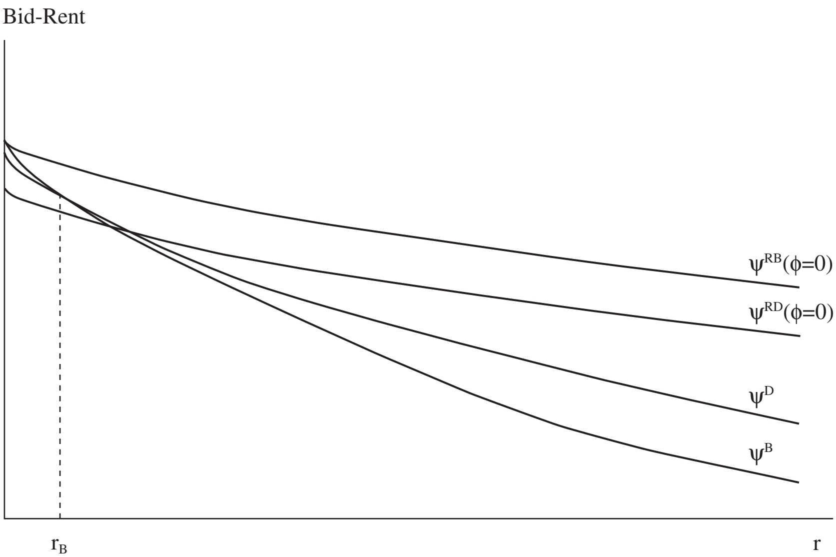
14. A minor extension of the model allowing commuters to walk to the rail line would imply (depending on walking speed) that a significant fraction of R_B commuters would actually be "walk and riders."

Figure 1. Rent Functions by Commuting Mode

Case 1: $b_B > b_R > b_D$

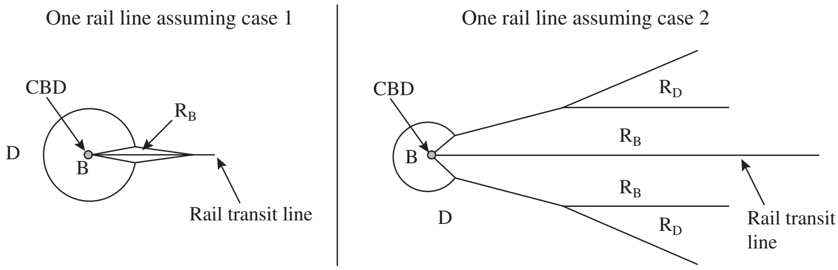


Case 2: $b_B > b_R > b_D$



Source: Authors' drawings based on the model.
r_B = radius at which people far from the rail line are indifferentbetween driving and taking the bus.
$r_{RB}(0)$ = radius along the rail line at which people are indifferent between driving and taking the rail line.

Figure 2. Equilibrium Commuting Mode Choice[a]



Source: Simulated equilibria calculated by the authors.

a. Lines show where identical agents are indifferent between commuting modes. The two figures are taken from analytical examples in which the ordering of travel speeds from fastest to slowest is driving, rail, bus in case 1 and rail, driving, bus in case 2. As the wage increases, the area of the bus region decreases.

value of land and population density near the rail line than the equilibrium without the rail line.

In case 2, the equilibrium pattern of commuting mode choice is more complicated. Since the rail line is now faster than driving, it is used all the way to the edge of the metropolitan area, assuming it extends that far. It induces some people who live very near the rail line but beyond r_B to get rid of their cars and use the bus (or their feet) and the rail line to commute. It also induces a potentially considerable segment of the population to "park and ride." The size of this group depends heavily on the speed premium the rail line has over driving and the full cost of driving.

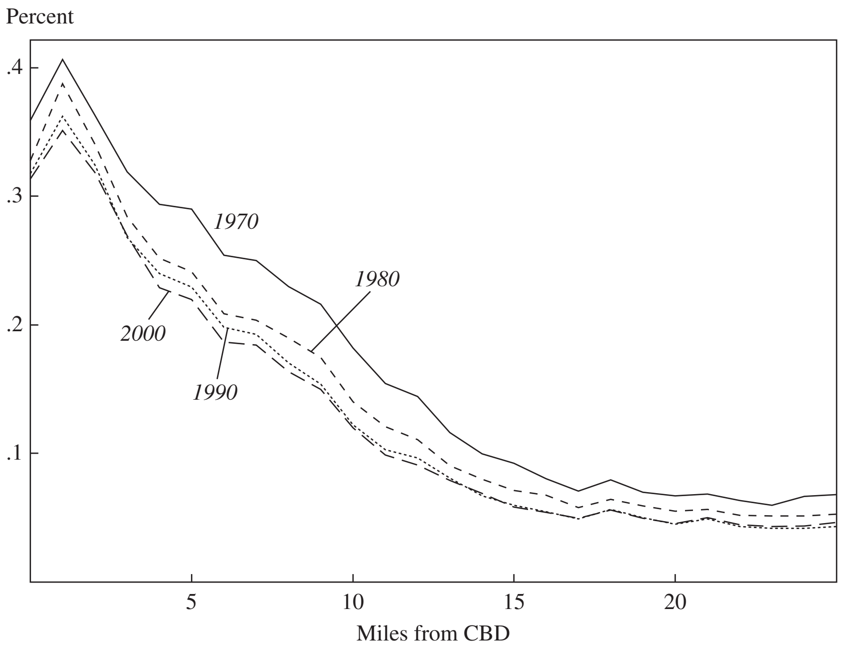
Broad Implications

Even though the model implies that a range of equilibria may ensue, it has some broad implications about behavioral responses to a new rail commuting option. The model suggests that most of the ridership on a new rail line is likely to be former bus users, though there will also be some former drivers. This is especially true if the speed of the rail line is between bus and driving speed. It also shows that most rail riders are likely to access the rail line via the bus (or on foot) if they live near the CBD, but by car if they live far away from the CBD. While only a segment of the population will use the rail line, everybody in the city enjoys a gross welfare gain because the rail line provides for a quicker commute for everybody, either through a shorter distance traveled or through a faster travel mode. Whether it is a net welfare gain depends, of course, on construction and operating costs.

In order for a new rail line to draw a significant number of people out of cars, it has to be fast enough to beat driving during rush hour and extend far enough into the suburbs to reach a significant number of people. Better rail transit access affects transit ridership differently in different parts of the metropolitan area. The region in which the effect is likely to be largest is beyond the distance where the switch occurs between mostly bus riders and mostly drivers.

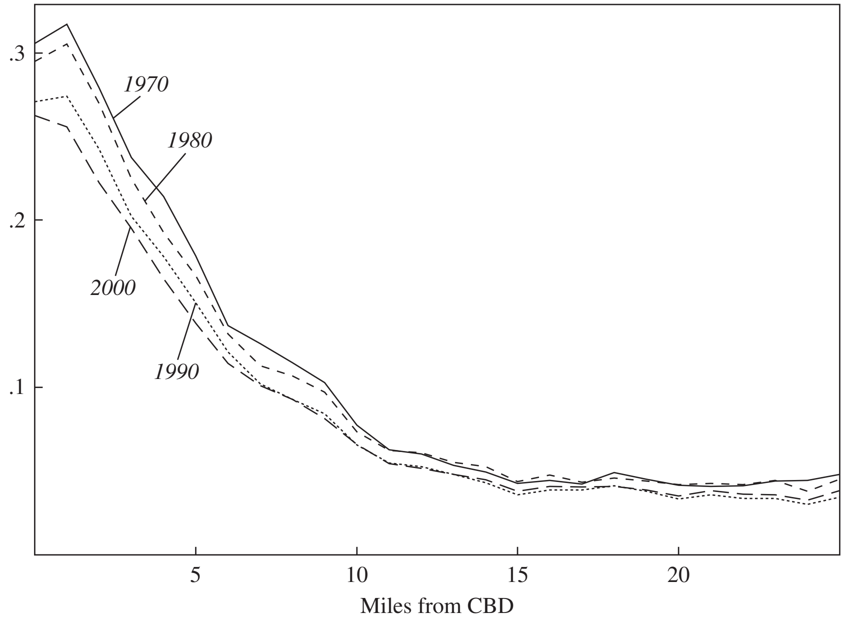
Figures 3 and 4 present some evidence that new rail lines were more successful at stemming declines in transit use in the suburbs than in the cities. We present the fraction of workers commuting by public transit as a function of the calendar year and distance to the CBD. Figure 3 shows that in 1970, 32 percent of workers (across 277 metropolitan areas) who lived three miles from the CBD commuted by public transit while 27 percent used transit in 2000. The fraction commuting by public transit declines in each decade within fifteen miles of the CBD, though it rises very slightly beyond fifteen miles between 1990 and 2000. Figure 4 presents a similar graph, but focuses on trends in tran-

Figure 3. Public Transit Use by Decade for All Metropolitan Areas, 1970–2000



Source: Authors' calculations using census micro data.

Figure 4. Public Transit Use by Decade for the Sixteen Cities That Expanded Rail Transit Systems between 1970 and 2000



Source: Authors' calculations using census micro data.

sit use only in the sixteen cities that significantly expanded their rail transit infrastructure between 1970 and 2000. Similar to figure 3, figure 4 demonstrates declining public transit use as distance to the CBD increases. However, metropolitan areas with rail transit improvements saw a much smaller decline over time in public transit use, especially between 1970 and 1980. The smaller decline in transit ridership in the treatment cities is particularly noticeable in the suburbs. Close to the city center, the share of workers commuting by public transit declined by about 5 percentage points between 1970 and 2000 in both sets of metropolitan areas. In contrast, the treated areas had declines of about 1 percentage point in the suburbs relative to about 4 percentage points in the full set of metropolitan areas.

It is worth noting two final points that would come as implications of a more general model. First, if transit does not serve very many commuting trips because of low employment and residential densities, it is not going to attract many riders. Second, if transit takes significantly longer than driving, it is only going to be used by the poor, because their low value of time makes them uniquely willing to avoid the fixed pecuniary cost of driving by taking transit. Together, these observations imply that transit riders are likely to be poorer in less centralized cities and that city centralization should be a good predictor of the success of new rail lines.

Rail Transit Supply

Throughout this paper we focus on how public transit use changes in census tracts that were close to rail transit in 2000 but not in 1970, relative to other tracts. Ideally, tracts would be randomly selected for treatment. We recognize, however, that the assignment process is unlikely to be random. In most metropolitan areas considering new transit projects, a regional planning organization devises a detailed plan that forms the basis of a funding request from the Federal Transit Administration. The planning processes used by these regional planning organizations are not systematic across metropolitan areas.[15] However, there are some systematic patterns in the location of transit lines that persist across metropolitan areas. For example, all rail transit systems in the United States are oriented to serve the CBD.[16] We show that in suburban areas, population density, income, and cost are all important predictors of the location of new rail transit.

Costs

Construction cost varies widely among rail transit lines in the United States. The least expensive lines are built on the surface, either as minor upgrades of little used existing freight railroad lines or built into city streets. These two types of construction usually cost less than $50 million per mile. The most expensive lines are bored tunnel, which in some cases have cost more than $300 million per mile (see table 1). Operating cost depends heavily on the type of rail transit. Light rail trolleys are generally less expensive per

15. Some systems, such as Bay Area Rapid Transit (BART) in San Francisco, were partially planned using sophisticated demand modeling based on Domencich and McFadden's (1975) techniques. Others, such as systems in San Diego and St. Louis, took advantage of existing rights of way as they were, with little attempt to alter them.

16. In some cases (Atlanta, San Francisco, Los Angeles, Washington), transit authorities have opted to serve the CBD through very high-cost tunneling. In other cases (Sacramento, San Jose, Dallas, San Diego) transit authorities sacrifice speed or convenience for cost and run the rail line on city streets or on existing railroad rights of way that skirt the city center.

revenue mile to operate than heavy rail. However, heavy rail trains can carry more passengers, so depending on loads they may have lower per-passenger operating costs.[17]

Federal funding typically covers between 50 and 75 percent of the cost of new rail transit construction. The Federal Transit Administration assigns funding under its New Starts program, based on an evaluation of proposals from local governments looking to build new transit lines. Every year it draws up a list of priority projects that get funded according to the amount of money allocated by Congress. There are a few lines built exclusively with local funding. It is very common for transit planners to underestimate construction costs and overestimate future ridership.[18]

While costs are usually mostly paid by the federal government, high-cost projects are less likely to be approved for funding, all else equal. Furthermore, state and local governments still have some cost incentive. Thus construction cost of potential lines is a key determinant of location in many metropolitan areas. The San Diego Trolley is a celebrated example of a low capital cost system. The original South Line runs on downtown streets for 1.7 miles and for 14.2 miles on an active freight railroad line. This choice of alignment was made as described in the following quote:

> According to McGean and others (1983), the major factor that led to the selected project alignment was the availability of the San Diego and Eastern railway. The property became available after a storm in 1976 washed out major portions of the roadbed. After the Interstate Commerce Commission refused to allow Southern Pacific Transportation Commission to abandon rail service on the line, MTDB was able to purchase the property for $18.1 million.[19]

Another example in which cost affected construction comes from Los Angeles. One branch of that city's Red Line, the Mid-City extension, was planned to run underneath Wilshire Boulevard toward Santa Monica from downtown Los Angeles. As reported in a 1996 review of Red Line progress by the U.S. General Accounting Office, "the design of the Mid-City extension was suspended following the discovery of high concentrations of hydrogen sulfide gas on the planned tunnel alignment. . . . The decision on the new alignment for Mid-City . . . is the single most costly increase currently

17. The difference between light rail and heavy rail is the weight of the transit vehicles. Light rail lines tend to run on power from overhead lines and heavy rail lines tend to run on third rail power, though there are a few exceptions.

18. See Pickrell (1989 and 1992), and Kain (1990).

19. Kain and Liu (1995, p. 5-3). MTDB is the Metropolitan Transit Development Board.

expected for the project."[20] The extra cost of building the Mid-City extension eventually killed the project.

It is very common for rail transit lines to be built on active or existing freight railroad lines. Of the sixteen cities that built or significantly expanded their rail transit systems between 1970 and 2000, thirteen used railroad rights of way for part of their systems. The portions of their systems on former railroad rights of way are most often in suburban areas, where potential ridership is not as sensitive to the exact location of the transit alignment.

Travel Demand

Table 4 compares two demand-side factors in census tracts within two kilometers of a rail transit line constructed between 1970 and 2000 to census tracts near transit lines existing in 1970 and census tracts not near a transit line in 2000. The table reports data on mean population density and household income for all sixteen metropolitan areas with significant rail transit expansions between 1970 and 2000.

In all cases, census tracts near rail transit in 1970 had much higher population densities than other tracts within the same cities. Among metropolitan areas receiving significant new rail transit after 1970, Chicago and San Francisco had average population density in tracts near transit of around 30,000 people per square mile relative to 8,000 people per square mile in tracts that never become rail transit accessible. Boston's average density near transit was somewhat less at 22,000 people per square mile. In all metropolitan areas except San Francisco, population density near transit lines that existed in 1970 declined between 1970 and 2000, in some places dramatically.[21]

In each old-transit city that received an infrastructure expansion since 1970, average population density in the set of tracts that experienced increased access to transit between 1970 and 2000 was between that of areas with transit in 1970 and that of areas that never received better transit access. In each new-transit city, average population density in areas near rail transit in 2000 was greater than other areas of the city. Density levels near new transit lines are much lower than near old transit lines. In many cities, population density levels near new transit lines are less than 5,000 people per square mile greater than average density in areas not near transit lines, indicating that while cities build lines to serve the greatest population possible, the decentralized residential

20. U.S. General Accounting Office (1996, pp. 6–7, 11).

21. In Cleveland, Philadelphia, and Pittsburgh, population density in census tracts near transit lines fell by more than 30 percent between 1970 and 2000.

Table 4. Comparison of Areas with and without Rail Transit, Population Density, and Mean Household Income, 1970–2000[a]

	Tracts with no transit				*Tracts with new transit 1970–2000*				*Tracts with transit in 1970*			
In thousands	*1970*	*1980*	*1990*	*2000*	*1970*	*1980*	*1990*	*2000*	*1970*	*1980*	*1990*	*2000*
Boston												
Population density	5	4	4	5	13	11	11	11	22	20	20	21
Mean household income	57	56	73	79	48	45	57	61	46	42	58	65
Chicago												
Population density	8	8	7	8	14	13	13	16	30	25	23	24
Mean household income	62	59	65	68	51	49	50	53	45	42	49	59
San Francisco												
Population density	8	7	7	8	11	10	11	12	29	27	29	31
Mean household income	61	60	79	94	47	44	54	63	45	45	58	74
Atlanta												
Population density	2	2	2	2	6	5	4	5				
Mean household income	55	52	65	70	43	39	49	61				
Baltimore												
Population density	7	6	5	5	20	17	16	14				
Mean household income	54	53	63	66	43	41	48	50				
Buffalo												
Population density	7	5	5	4	17	12	12	11				
Mean household income	51	46	47	51	40	35	37	38				
Dallas												
Population density	4	3	4	5	7	7	7	9				
Mean household income	55	53	61	68	43	40	47	55				
Denver												
Population density	5	4	4	5	12	10	9	10				
Mean household income	53	53	56	68	31	30	33	45				

continued on next page

Table 4. Comparison of Areas with and without Rail Transit, Population Density, and Mean Household Income, 1970–2000[a] (continued)

	Tracts with no transit				*Tracts with new transit 1970–2000*				*Tracts with transit in 1970*			
In thousands	*1970*	*1980*	*1990*	*2000*	*1970*	*1980*	*1990*	*2000*	*1970*	*1980*	*1990*	*2000*
Los Angeles												
Population density	9	9	11	12	14	17	21	23				
Mean household income	54	54	67	65	37	35	41	40				
Miami												
Population density	7	7	8	8	11	10	11	11				
Mean household income	49	47	53	55	41	39	44	49				
Portland												
Population density	4	3	3	4	7	6	6	6				
Mean household income	47	49	53	61	47	44	48	54				
Sacramento												
Population density	4	4	5	5	5	5	6	6				
Mean household income	51	49	57	62	39	37	44	45				
San Diego												
Population density	6	6	7	7	8	7	9	10				
Mean household income	51	53	66	70	43	38	45	47				
San Jose												
Population density	6	6	7	8	7	7	8	9				
Mean household income	61	60	82	101	48	50	65	81				
St. Louis												
Population density	6	4	4	3	12	8	7	6				
Mean household income	51	47	55	60	37	34	35	38				
Washington												
Population density	6	4	5	5	14	12	12	12				
Mean household income	69	68	84	88	56	56	67	72				

Source: Authors' calculations.

a. Includes all census tracts within twenty-five miles of a transit central business district. Population density is thousands of people per square mile, mean household income in thousands of 1999 dollars.

population makes reaching a large number of people difficult. Los Angeles is the only city where population density in newly transit-accessible areas increased by more than 3,000 people between 1970 and 2000 and where the average population density near new transit exceeded 20,000 in 2000. In Los Angeles, population density monotonically increased from 13,000 people per square mile in 1970 to 23,000 people per square mile in 2000 in newly rail accessible tracts. The declining metropolitan areas of Baltimore, Buffalo, and St. Louis each saw population density near new transit lines drop by about 6,000 people per square mile between 1970 and 2000.

Optimal allocation of rail lines across space would connect areas with high population and employment densities. Unfortunately, detailed historical data on the spatial distribution of employment are not readily available. However, because the CBD is the location of both the transit hub and the highest concentration of employment in every metropolitan area, employment density must be an important determinant of construction priorities. We present further evidence supporting this claim below.

In all cities, mean real household income in new rail transit-accessible areas is below that in other areas, with the gap widening between 1970 and 2000 in all cities except Atlanta and Miami. This widening of the income gap occurs after the new rail lines opened, supporting the prediction of the model in the previous section and the point made by Glaeser, Kahn, and Rappaport that public transit is a poverty magnet.[22] Other demographic attributes such as race, gender, age, and schooling may also influence planners' location decisions for new rail transit because they may reflect differences between wealth and annual income, differences between labor and nonlabor income, or both.

Table 4 shows that new transit was built in parts of metropolitan areas that were denser and poorer than other areas. Part of this is because new rail lines always pass through the CBD. However, as the following section shows, density and income still explain variation in rail transit access, even conditional on CBD distance.

Relative Importance of Cost and Demand

Table 5 evaluates more systematically the locations at which new transit lines have been built. Each column of the table reports a separate OLS regression. The sample includes only census tracts whose centroids were at least two kilometers from the nearest rail transit line in the initial year. The dependent

22. Glaeser, Kahn, and Rappaport (2000).

Table 5. Explaining the Location of Rail Transit Construction[a]

	Tract moving to within 2 km of rail transit				
	1970–2000 All rail MSA tracts		*1994–04 California only*		
	1	*2*	*3*	*4*	*5*
Log population density	0.028	0.023	0.010	0.009	0.008
	(0.005)**	(0.005)**	(0.006)	(0.006)	(0.006)
Distance to CBD	–0.031	–0.031	–0.017	–0.018	–0.017
	(0.002)**	(0.002)**	(0.003)**	(0.003)**	(0.003)**
Distance to CBD squared	0.001	0.001	0.000	0.000	0.000
	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**
Distance to nearest	–0.056	–0.055	–0.006	–0.004	–0.003
railroad	(0.005)**	(0.005)**	(0.006)	(0.006)	(0.006)
Distance to railroad	0.003	0.003	0.001	0.001	0.001
squared	(0.000)**	(0.000)**	(0.000)	(0.000)	(0.000)
Log employment in	. . .	0.025	. . .	0.014	0.014
zip code of tract	. . .	(0.005)**	. . .	(0.006)*	(0.006)*
Fraction voting in favor	. . .	. . .	. . .	. . .	0.229
of Proposition 185	. . .	. . .	. . .	. . .	(0.116)*
Log household income	–0.203	–0.205	–0.076	–0.074	–0.048
	(0.026)**	(0.025)**	(0.027)**	(0.027)**	(0.030)
Fraction over sixty-five	0.297	0.298	–0.041	–0.054	–0.091
	(0.111)**	(0.112)**	(0.098)	(0.099)	(0.100)
Fraction female	–0.661	–0.673	–0.586	–0.577	–0.500
	(0.140)**	(0.134)**	(0.240)*	(0.236)*	(0.234)*
Fraction black	0.148	0.164	–0.034	–0.020	–0.020
	(0.026)**	(0.026)**	(0.052)	(0.053)	(0.052)
Fraction with	0.424	0.424	0.041	0.036	–0.075
college degree	(0.064)**	(0.063)**	(0.061)	(0.061)	(0.080)
Baltimore	–0.030	–0.021	. . .	. . .	. . .
	(0.031)	(0.032)	. . .	. . .	. . .
Boston	–0.132	–0.118	. . .	. . .	. . .
	(0.030)**	(0.031)**	. . .	. . .	. . .
Buffalo	–0.148	–0.134	. . .	. . .	. . .
	(0.037)**	(0.038)**	. . .	. . .	. . .
Chicago	–0.174	–0.178	. . .	. . .	. . .
	(0.031)**	(0.030)**	. . .	. . .	. . .
Dallas	–0.134	–0.131	. . .	. . .	. . .
	(0.035)**	(0.035)**	. . .	. . .	. . .
Denver	–0.264	–0.259	. . .	. . .	. . .
	(0.031)**	(0.032)**	. . .	. . .	. . .
Los Angeles	–0.102	–0.091	(omitted group)		
	(0.028)**	(0.029)**	. . .	. . .	. . .
Miami	–0.085	–0.079	. . .	. . .	. . .
	(0.037)*	(0.038)*	. . .	. . .	. . .

continued on next page

Table 5. Explaining the Location of Rail Transit Construction[a] (continued)

	Tract moving to within 2 km of rail transit				
	1970–2000 All rail MSA tracts		*1994–04 California only*		
	1	*2*	*3*	*4*	*5*
Portland	–0.054	–0.045	. . .	. . .	. . .
	(0.044)	(0.044)	. . .	. . .	. . .
Sacramento	–0.096	–0.083	–0.037	–0.032	–0.028
	(0.037)*	(0.038)*	(0.024)	(0.025)	(0.025)
San Diego	0.064	0.074	–0.085	–0.087	–0.081
	(0.038)	(0.038)	(0.022)**	(0.022)**	(0.022)**
San Francisco	0.147	0.163	0.032	0.034	0.017
	(0.034)**	(0.035)**	(0.022)	(0.022)	(0.025)
San Jose	–0.110	–0.103	–0.023	–0.025	–0.033
	(0.032)**	(0.032)**	(0.021)	(0.021)	(0.022)
St. Louis	–0.152	–0.140	. . .	. . .	. . .
	(0.034)**	(0.034)**	. . .	. . .	. . .
Washington	0.179	0.191	. . .	. . .	. . .
	(0.030)**	(0.031)**	. . .	. . .	. . .
Constant	2.912	2.752	1.454	1.307	0.965
	(0.281)**	(0.282)**	(0.331)**	(0.336)**	(0.371)**
Number of observations	7,112	7,042	3,200	3,200	3,200
R-squared	0.32	0.33	0.12	0.12	0.12

Source: Authors' calculations.

a. Each column is a separate linear probability model. Sample includes only census tracts with centroids greater than two kilometers from the nearest rail transit line in the initial year. Atlanta is the omitted group in specifications 1 and 2. Los Angeles is the omitted group in specifications 3–5. Demographics are from 1970 in specifications 1 and 2 and 1990 in specifications 3–5.

*Significance at the 5 percent level.

**Significance at the 1 percent level.

variable is an indicator that equals one if new rail transit construction means that a tract becomes within two kilometers of a new rail line between the base year and end year. These regressions show which observable characteristics of census tracts predict increased transit access. We run one version including all cities with significant transit expansions since 1970 and another version using only cities in California starting in 1994. All explanatory variables are set at their base year (1970 in columns 1 and 2, 1990 or 1994 in columns 3, 4, and 5). The regression equation is as follows:

$$\Delta 1\left(dis \leq 2km\right)_{jk} = \alpha_k + \gamma_1 ldens_{jk} + \beta_1 r_{jk} + \beta_2 r_{jk}^2 + c_1 d_{jk} + c_2 d_{jk}^2 + \bar{X}_{jk}\delta \\ \left(+ \gamma_2 emp_{m(jk)} + \gamma_3 pro185_{jk}\right) + \varepsilon_{jk},$$

where k indexes metropolitan statistical area (MSA), j indexes tract, and m indexes zip code. We include MSA fixed effects, a quadratic in distance to the

CBD, a quadratic in distance to the nearest railroad right of way, demographics in the initial year, and log population density in the initial year. In some specifications we also include the log employment of the zip code in which the census tract was located in 1994 and the fraction of tract residents voting for Proposition 185 in California, which provided funding for public transit expansions. Each coefficient measures the change in probability of receiving transit in the tract associated with increasing the given variable by one.

All else equal, census tracts with higher population densities that are closer to the CBD, closer to a railroad line, and have a demographic mix that includes more senior citizens, men, blacks, and the poor, are more likely to have improved rail transit access. Across metropolitan areas, there are large differences in the extent of new rail transit lines. Relative to the omitted category of Atlanta, observationally identical Denver tracts were 26 percent less likely to receive increased rail transit access while San Francisco tracts were 15 percent more likely to receive increased access between 1970 and 2000. The specification in table 5, column 2 includes the log of the tract zip code's total employment in 1994. We use 1994 because it is the earliest year in which we have disaggregated data. It shows a positive association between the location of employment and rail lines, even conditional on distance to the CBD. We hesitate to interpret this coefficient causally because of the long lag in timing.

The last three columns of table 5 estimate the rail transit supply equation restricting the sample to census tracts in California and examining rail transit expansion between 1994 and 2004. Recent construction in California is of particular interest because we observe local support for Proposition 185 in 1994, which was a binding referendum to fund transportation improvements, including rail transit expansions.[23] Further, there was significant post-1994

23. Proposition 185 says: "This measure imposes a 4 percent sales tax on gasoline not diesel fuel beginning January 1, 1995. This new sales tax is in addition to the existing 18 cents per gallon state tax on gasoline and diesel fuel and the average sales tax of approximately 8 percent imposed by the state and local governments on all goods, including gasoline. Revenues generated by the increased tax will be used to improve and operate passenger rail and mass transit bus services, and to make specific improvements to streets and highways. The measure also contains various provisions that generally place restrictions on the use of certain state and local revenues for transportation purposes. . . . Proponents include officials from the Congress of California Seniors, the Coalition for Clean Air, the Planning and Conservation League, Citizens for Reliable and Safe Highways, and the California Public Interest Research Group. . . . Opponents include officials from the California Transportation Commission, the California Highway Users Conference, the California Taxpayers' Association, the California Business Alliance, and the Alliance of California Taxpayers and Involved Voters." Mary Beth Barber, "Proposition 185: Public Transportation Trust Funds, Gasoline Sales Tax," *California Online Voter Guide,* Fall, 1994, (www.calvoter.org).

rail transit construction in California with a lot of variation in rail transit access improvements in California cities. Controlling for demographic observables, we find that census tracts differ with respect to their unobserved taste for increased transit access. Conditional on other observables, tracts giving 10 percentage points greater support to Proposition 185 were 2 percent more likely to receive access to new rail transit between 1994 and 2004.[24] We view this effect as small.

Transit Use Trends within and across Metropolitan Areas

The theoretical model presented above provides several clear and general predictions about the spatial distribution of commuting mode choice. The model predicts that transit use should be greater near the CBD than in the suburbs. Further, rail users who live near the center are likely to walk or take the bus a short distance to the rail line while rail users in the suburbs (if they exist) are more likely to drive to the rail line and may travel a longer distance to get there. We emphasize that because the model is based in an environment in which employment occurs only at one location, we should not expect mode choice levels in the data to be as clear-cut as in the model. We should, however, expect spatial patterns of transit use to follow the model's predictions.

Spatial Distribution of Commuting Mode Choice

Table 6 shows the evolution over time of the fraction of commuters using public transit by distance to rail transit and distance to the CBD, pooling data from all sixteen cities. Many of the patterns in table 6 follow predictions from the model. Transit has a smaller commuting market share further from CBDs. Transit use declines more quickly as a function of distance around rail lines nearer to CBDs than those further from CBDs. However, base transit use in areas not near rail lines is higher near CBDs. This pattern can be interpreted as showing that more center-city dwellers commute by bus than do suburbanites. However, the rail line influences a smaller area near the CBD than in the suburbs. These are predictions that come straight out of the model. This pattern

24. Some of the discrepancies between influences on nationwide rail transit construction since 1970 and construction in California since 1994 are explained by the fact that by 1994, all major cities in California already had rail transit lines running through their CBDs. It may also be that given the success of Proposition 185, California cities were less dependent on federal funding and the associated requirements for new rail transit lines to serve poorer, denser areas.

Table 6. Transit Use by CBD Distance and Distance to Transit, 1970–2000[a]

CBD distance	*Distance to nearest rail line*	*Nearest rail transit line in 2000 existed in 1970*				*Nearest rail transit line in 2000 did not exist in 1970*			
		1970	*1980*	*1990*	*2000*	*1970*	*1980*	*1990*	*2000*
0–2.5km	0–500 m	0.38	0.33	0.32	0.32	0.32	0.32	0.30	0.29
	500–1000 m	0.37	0.38	0.35	0.33	0.28	0.25	0.21	0.18
	1–2 km	0.41	0.42	0.36	0.34	0.23	0.22	0.17	0.15
	>2 km	0.41	0.40	0.32	0.33	0.21	0.18	0.13	0.14
2.5–5km	0–500 m	0.41	0.39	0.36	0.36	0.34	0.36	0.35	0.31
	500–1000 m	0.43	0.38	0.36	0.32	0.32	0.30	0.28	0.25
	1–2 km	0.41	0.39	0.34	0.32	0.23	0.23	0.20	0.17
	>2 km	0.45	0.44	0.35	0.32	0.19	0.17	0.14	0.12
5–10km	0–500 m	0.42	0.38	0.38	0.37	0.24	0.23	0.23	0.22
	500–1000 m	0.39	0.36	0.33	0.32	0.21	0.22	0.20	0.18
	1–2 km	0.40	0.36	0.32	0.29	0.19	0.18	0.16	0.15
	>2 km	0.30	0.28	0.25	0.24	0.12	0.12	0.10	0.09
10–20km	0–500 m	0.40	0.37	0.34	0.32	0.11	0.13	0.13	0.15
	500–1000 m	0.34	0.30	0.27	0.24	0.11	0.14	0.14	0.14
	1–2 km	0.31	0.27	0.23	0.20	0.09	0.10	0.10	0.10
	> 2 km	0.22	0.19	0.17	0.15	0.05	0.06	0.05	0.05
>20km	0–500 m	0.22	0.23	0.18	0.17	0.07	0.09	0.12	0.11
	500–1000 m	0.26	0.29	0.21	0.22	0.06	0.09	0.10	0.11
	1–2 km	0.15	0.16	0.14	0.13	0.05	0.07	0.07	0.09
	> 2 km	0.12	0.10	0.09	0.08	0.03	0.04	0.03	0.03

Source: Authors' calculations.

a. Sample includes all census tracts within twenty-five miles of the CBD of all cities listed in table 1. Each entry is the fraction commuting by public transit in the given location and year pooled across cities.

is weaker near rail lines that existed in 1970, likely because bus networks in old-transit cities are more widespread within ten kilometers of the CBD than those in new-transit cities. Cross-sectional comparisons in table 6 also show the decreasing marginal return to building new rail lines. The level of transit ridership is greater near old rail lines than new ones.

Patterns over time in table 6 also give an indication of how new rail transit has affected use over time. Overall transit use fell in all cells between 1970 and 2000 except for areas within two kilometers of new rail lines that are at least ten kilometers from the CBD. This is the same area that the model says is most likely to be affected by a new rail line because it is where drivers are most likely to switch to a faster rail line. Within ten kilometers of the CBD, transit use fell less quickly in areas within two kilometers of old and new rail lines than in other areas. Rail lines have reduced the decline in transit ridership in cities while spurring growing (but low) ridership in the suburbs. Use of rail lines that existed in 1970 has been monotonically falling almost everywhere, though it remains at a higher level than use of rail lines built since 1970.

It is not surprising that transit use has been falling in areas where transit access has changed little. Suburbanization of employment and residences has made it less likely for transit to be a feasible commuting alternative. Further, wages have been growing, increasing people's value of commuting time, thereby making them less likely to commute by bus or rail lines that are slower than driving.

While table 6 provides a general sense of trends in the spatial distribution of transit use over time, it aggregates across metropolitan areas with very different urban structures. Table 7 breaks down trends in the spatial distribution of transit use by metropolitan area. The table shows that in all metropolitan areas except for Chicago, transit use in suburban areas grew faster within two kilometers of new rail lines than elsewhere. Further, in all metropolitan areas except for Buffalo and Chicago, rail transit use rose between 1970 and 2000 in suburban areas that received new rail transit access.[25] In Washington, San Francisco, Los Angeles, and Boston, transit use grew at least 2 percentage points faster in newly accessible areas near the CBD than in other areas. The same is true for areas around rail transit lines that existed in 1970 in Boston and San Francisco.

Table 7 gives a good indication of the relative success of new rail transit lines in different metropolitan areas. In the declining cities of Baltimore, Buffalo, and St. Louis, new rail transit lines have not had a significant effect in reversing the exodus of city residents from transit. In Chicago, transit use has been falling faster near rail lines than in other areas, though Chicago started from a higher base level of transit use. Rail transit has been more successful at keeping riders on old rail lines and drawing riders to new rail lines in Boston, Los Angeles, San Francisco, and Washington.

Empirical Specification

In table 1, we documented that different cities experienced rail transit expansions in different years. We now seek to exploit this variation in the timing of treatments to estimate profiles of the impacts of improved access to rail transit on transit use for each city over time. Panel A of table 8 reports results from ordinary least squares (OLS) regressions that give difference-

25. This represents only one census tract in Buffalo since the rail line in Buffalo is less than ten kilometers long.

Table 7. Transit Use by City, 1970–2000[a]

City	*Distance to CBD*	*Distance to rail*	*Nearest rail transit line in 2000 existed in 1970*				*Nearest rail transit line in 2000 did not exist in 1970*			
			1970	*1980*	*1990*	*2000*	*1970*	*1980*	*1990*	*2000*
Boston	<10 km	<2 km	0.38	0.33	0.32	0.33	0.29	0.25	0.25	0.27
	<10 km	>2 km	0.26	0.21	0.18	0.19	0.23	0.20	0.17	0.17
	>10 km	<2 km	0.17	0.16	0.13	0.14	0.12	0.17	0.15	0.17
	>10 km	>2 km	0.10	0.07	0.07	0.08	0.07	0.06	0.05	0.07
Chicago	<10 km	<2 km	0.43	0.39	0.37	0.34	0.35	0.31	0.27	0.22
	<10 km	>2 km	0.34	0.32	0.27	0.26	0.26	0.21	0.19	0.17
	>10 km	<2 km	0.35	0.32	0.29	0.26	0.27	0.23	0.20	0.15
	>10 km	>2 km	0.19	0.15	0.14	0.12	0.13	0.10	0.08	0.07
San Francisco	<10 km	<2 km	0.37	0.40	0.35	0.33	0.30	0.37	0.34	0.31
	<10 km	>2 km	0.39	0.40	0.33	0.30	0.24	0.22	0.21	0.23
	>10 km	<2 km	0.34	0.34	0.32	0.32	0.12	0.16	0.15	0.16
	>10 km	>2 km	0.12	0.13	0.14	0.14	0.08	0.09	0.08	0.08
			Nearest rail transit line in 2000 did not exist in 1970							
			< 10 km from CBD				*> 10 km from CBD*			
			1970	*1980*	*1990*	*2000*	*1970*	*1980*	*1990*	*2000*
Atlanta	. . .	<2 km	0.25	0.27	0.22	0.17	0.05	0.08	0.11	0.12
		>2 km	0.13	0.20	0.17	0.13	0.03	0.04	0.03	0.03
Baltimore	. . .	<2 km	0.32	0.30	0.26	0.23	0.05	0.05	0.05	0.05
		>2 km	0.18	0.17	0.15	0.13	0.04	0.04	0.03	0.03
Buffalo[b]	. . .	<2 km	0.22	0.18	0.15	0.13	0.10	0.09	0.05	0.07
		>2 km	0.18	0.13	0.09	0.08	0.04	0.03	0.02	0.01

Dallas	. . .	<2 km	0.17	0.14	0.11	0.08	0.05	0.07	0.07	0.09
		>2 km	0.15	0.12	0.10	0.07	0.01	0.02	0.02	0.02
Denver[c]	. . .	<2 km	0.13	0.16	0.14	0.13	. . .	. . .	. . .	. . .
		>2 km	0.06	0.09	0.07	0.08	0.02	0.05	0.03	0.04
Los Angeles	. . .	<2 km	0.23	0.26	0.27	0.26	0.05	0.07	0.07	0.08
		>2 km	0.15	0.16	0.15	0.14	0.03	0.04	0.04	0.04
Miami	. . .	<2 km	0.19	0.16	0.14	0.12	0.03	0.03	0.04	0.05
		>2 km	0.15	0.12	0.12	0.09	0.03	0.03	0.03	0.03
Portland	. . .	<2 km	0.11	0.16	0.12	0.15	0.04	0.08	0.06	0.09
		>2 km	0.09	0.14	0.10	0.12	0.02	0.04	0.03	0.04
Sacramento	. . .	<2 km	0.07	0.07	0.05	0.07	0.01	0.04	0.04	0.05
		>2 km	0.03	0.04	0.03	0.04	0.01	0.03	0.02	0.02
San Diego		<2 km	0.11	0.08	0.09	0.08	0.01	0.02	0.04	0.05
		>2 km	0.04	0.05	0.06	0.06	0.02	0.02	0.02	0.02
San Jose		<2 km	0.04	0.04	0.05	0.07	0.02	0.04	0.04	0.05
		>2 km	0.02	0.03	0.03	0.04	0.03	0.04	0.03	0.03
St. Louis		<2 km	0.28	0.26	0.17	0.16	0.06	0.07	0.05	0.07
		>2 km	0.18	0.16	0.11	0.10	0.03	0.03	0.01	0.01
Washington		<2 km	0.34	0.35	0.35	0.32	0.09	0.13	0.17	0.18
		>2 km	0.24	0.25	0.23	0.19	0.05	0.07	0.08	0.08

a. Each entry is the fraction commuting by public transit in the given location. The sample includes only census tracts within twenty-five miles of the CBD of each city.
b. The Buffalo transit use numbers < 2 km from the light rail line and > 10 km from the CBD reflect data from only one census tract.
c. Denver had no rail transit infrastructure at least ten kilometers from the CBD in 2000.

Table 8. Changes in Public Transit Use over Time, by City[a]

	Panel A: Ten-year differences					
	Specification 1		*Specification 2*		*Specification 3*	
Distance to CBD	*<10 km*	*>10 km*	*<10 km*	*>10 km*	*<10 km*	*>10 km*
Atlanta (1970s)	0.030	0.063	0.015	0.048	–0.043	0.016
	(0.010)**	(0.041)	(0.010)	(0.039)	(0.011)**	(0.038)
(1980s)[c]	–0.022	0.062	–0.022	0.062	–0.007	0.067
	(0.008)**	(0.010)**	(0.008)**	(0.010)**	(0.010)	(0.010)**
(1990s)	0.001	0.022	–0.001	0.019	0.034	0.023
	(0.038)	(0.008)**	(0.038)	(0.009)*	(0.038)	(0.009)**
Baltimore (1980s)	–0.038	0.035	–0.034	0.039	–0.008	0.040
	(0.007)**	(0.011)**	(0.007)**	(0.011)**	(0.008)	(0.011)**
(1990s)[c]	–0.006	0.007	–0.006	0.007	0.004	0.008
	(0.007)	(0.008)	(0.007)	(0.008)	(0.008)	(0.008)
Boston (1970s)[c]	–0.016	0.060	0.002	0.079	0.028	0.094
	(0.011)	(0.015)**	(0.011)	(0.014)**	(0.011)*	(0.014)**
(1980s)	0.003	–0.008	0.001	–0.010	0.019	–0.007
	(0.010)	(0.015)	(0.010)	(0.014)	(0.010)	(0.014)
Buffalo (1980s)[c]	–0.020	–0.039	–0.013	–0.032	0.012	–0.024
	(0.008)*	(0.040)	(0.009)	(0.039)	(0.010)	(0.039)
Chicago (1970s)	. . .	–0.025	. . .	0.002	. . .	0.020
	. . .	(0.010)*	. . .	(0.009)	. . .	(0.009)*
(1980s)	. . .	–0.005	. . .	0.007	. . .	0.008
	. . .	(0.010)	. . .	(0.010)	. . .	(0.010)
(1990s)[c]	–0.058	–0.032	–0.045	–0.019	–0.019	0.000
	(0.009)**	(0.009)**	(0.009)**	(0.009)*	(0.010)	(0.009)
Dallas (1990s)[c]	–0.033	0.020	–0.031	0.021	–0.009	0.031
	(0.005)**	(0.010)*	(0.005)**	(0.010)*	(0.007)	(0.010)**
Denver (1990s)[c]	–0.015	. . .	–0.021	. . .	–0.025	. . .
	(0.007)*	. . .	(0.007)**	. . .	(0.008)**	. . .
Los Angeles (1990s)[c]	0.001	0.010	–0.002	0.007	0.009	0.008
	(0.003)	(0.003)**	(0.003)	(0.003)*	(0.004)*	(0.003)*

Miami (1980s)[c]	–0.001	0.019	–0.010	0.010	–0.007	0.011
	(0.007)	(0.008)*	(0.007)	(0.008)	(0.009)	(0.008)
Portland (1980s)	–0.029	–0.008	–0.017	0.003	0.008	0.001
	(0.007)**	(0.009)	(0.007)*	(0.009)	(0.008)	(0.009)
(1990s)[c]	0.038	0.037	0.028	0.027	0.023	0.027
	(0.012)**	(0.007)**	(0.012)*	(0.007)**	(0.012)	(0.007)**
Sacramento (1980s)[c]	–0.009	0.002	–0.007	0.004	–0.008	0.004
	(0.007)	(0.012)	(0.008)	(0.012)	(0.010)	(0.012)
(1990s)	. . .	0.001	. . .	–0.003	. . .	–0.004
	. . .	(0.017)	. . .	(0.017)	. . .	(0.017)
San Diego (1980s)[c]	0.002	0.027	–0.002	0.023	0.001	0.022
	(0.007)	(0.006)**	(0.007)	(0.006)**	(0.008)	(0.006)**
(1990s)	–0.002	0.004	–0.002	0.005	0.006	0.002
	(0.007)	(0.011)	(0.007)	(0.012)	(0.008)	(0.011)
San Francisco (1970s)[c]	–0.011	0.039	–0.022	0.027	–0.034	0.026
	(0.029)	(0.004)**	(0.028)	(0.004)**	(0.028)	(0.004)**
(1990s)	–0.028	0.007	–0.027	0.008	–0.012	0.008
	(0.041)	(0.009)	(0.040)	(0.009)	(0.040)	(0.009)
San Jose (1980s)	0.025	–0.005	0.022	–0.008	0.009	–0.009
	(0.009)**	(0.033)	(0.009)*	(0.033)	(0.010)	(0.032)
(1990s)[c]	0.010	0.006	0.009	0.005	0.008	0.005
	(0.007)	(0.006)	(0.008)	(0.006)	(0.008)	(0.006)
St. Louis (1990s)[c]	–0.002	0.012	–0.001	0.013	–0.001	0.013
	(0.009)	(0.010)	(0.009)	(0.010)	(0.010)	(0.010)
Washington (1970s)	0.019	0.113	–0.002	0.092	0.022	0.092
	(0.005)**	(0.011)**	(0.005)	(0.010)**	(0.007)**	(0.010)**
(1980s)[c]	0.024	0.079	0.010	0.066	0.015	0.064
	(0.007)**	(0.005)**	(0.007)	(0.005)**	(0.008)*	(0.005)**
(1990s)	–0.021	0.029	–0.020	0.030	0.014	0.040
	(0.009)*	(0.005)**	(0.009)*	(0.005)**	(0.010)	(0.006)**
Initial year rail access	Yes		Yes		Yes	
MSA Fixed Effects	No		Yes		Yes	
(CBD Dis)*(MSA FE)	No		No		Yes	
(CBD Dis^2)*(MSA FE)	No		No		Yes	

continued on next page

Table 8. Changes in Public Transit Use over Time, by City[a] (continued)

	Panel B: Twenty- and thirty-year differences[b]					
	Specification 1		*Specification 2*		*Specification 3*	
Distance to CBD	*<10 km*	*>10 km*	*<10 km*	*>10 km*	*<10 km*	*>10 km*
			Twenty years			
Atlanta (1980–2000)	–0.058	0.058	–0.060	0.056	–0.015	0.069
	(0.010)**	(0.011)**	(0.009)**	(0.011)**	(0.011)	(0.011)**
Baltimore (1980–2000)	–0.050	0.031	–0.048	0.032	–0.011	0.036
	(0.008)**	(0.013)*	(0.008)**	(0.013)*	(0.010)	(0.013)**
Boston (1970–90)	0.003	0.044	0.020	0.060	0.063	0.085
	(0.014)	(0.018)*	(0.013)	(0.017)**	(0.014)**	(0.017)**
Buffalo (1980–2000)	–0.035	–0.013	–0.020	0.002	0.004	0.009
	(0.009)**	(0.045)	(0.010)*	(0.044)	(0.011)	(0.043)
Chicago (1970–90)	. . .	–0.083	. . .	–0.046	. . .	–0.019
	. . .	(0.012)**	. . .	(0.011)**	. . .	(0.012)
Miami (1980–2000)	–0.009	0.027	–0.018	0.018	0.006	0.024
	(0.007)	(0.009)**	(0.008)*	(0.009)	(0.010)	(0.009)**
Portland (1980–2000)	–0.008	0.015	–0.007	0.016	0.012	0.014
	(0.008)	(0.011)	(0.008)	(0.011)	(0.010)	(0.010)
Sacramento (1980–2000)	0.003	0.018	0.001	0.016	0.001	0.016
	(0.008)	(0.014)	(0.009)	(0.014)	(0.011)	(0.014)
San Diego (1980–2000)	–0.010	0.034	–0.014	0.029	–0.003	0.028
	(0.008)	(0.007)**	(0.008)	(0.007)**	(0.010)	(0.007)**
San Francisco (1970–90)	–0.046	0.029	–0.053	0.022	–0.010	0.022
	(0.036)	(0.005)**	(0.034)	(0.005)**	(0.034)	(0.005)**
San Jose (1980–2000)	0.047	–0.014	0.042	–0.019	0.026	–0.019
	(0.011)**	(0.038)	(0.011)**	(0.037)	(0.012)*	(0.036)
Washington (1970–90)	0.021	0.148	–0.018	0.109	0.012	0.109
	(0.006)**	(0.013)**	(0.006)**	(0.012)**	(0.009)	(0.012)**

			Thirty years			
Boston (1970–2000)	0.024	0.078	0.022	0.076	0.067	0.102
	(0.015)	(0.020)**	(0.015)	(0.019)**	(0.015)**	(0.019)**
Chicago (1970–2000)	. . .	–0.126	. . .	–0.084	. . .	–0.036
	. . .	(0.014)**	. . .	(0.013)**	. . .	(0.013)**
San Francisco (1970–2000)	0.008	0.045	–0.004	0.033	0.049	0.034
	(0.040)	(0.005)**	(0.038)	(0.006)**	(0.037)	(0.006)**
Washington (1970–2000)	–0.003	0.137	–0.045	0.095	0.035	0.113
	(0.007)	(0.015)**	(0.007)**	(0.014)**	(0.010)**	(0.014)**
Observations	3,653		3,653		3,653	
R-Squared	0.23		0.33		0.39	

Source: Authors' calculations.

*Significance at the 5 percent level.

**Significance at the 1 percent level.

a. Estimates produced from regressions of the change in the fraction of commuters using public transit on indicators for being within two kilometers of a rail line that opened in the first decade of the difference. Each regression controls for being close to transit in the base year. Sample includes all census tracts within twenty-five miles of the CBD of each city listed in table 1, except twelve tracts in Boston and thirty-six tracts in Chicago that got further away from transit between 1970 and 2000 and seventy-two tracts in the San Jose area that were closer to a BART line to San Francisco than a VTA light rail line serving San Jose in 2000. Atlanta is excluded from the thirty-year difference because its first rail line opened in 1979.

b. Twenty- and thirty-year differences also control for becoming close to a transit line in the decade before the end year. In addition, the thirty-year differences control for becoming close to a rail line two decades before the end year. Additional controls in the twenty- and thirty-year regressions are enumerated at the bottom of Panel A. Each regression is weighted by the number of commuters in 2000.

c. Decade in which the largest expansion took place for listed city.

in-difference type estimates of the ridership gains due to new rail lines. The equation estimated in specification 3 is:

$$\begin{aligned}\Delta \frac{T_{jk}}{C_{jk}} &= \alpha_k + \gamma_{1k} 1\left(dis_{jk}^{CBD} < 10, \Delta D_{jk}^{RAIL} = 1\right) + \gamma_{2k} 1\left(dis_{jk}^{CBD} > 10, \Delta D_{jk}^{RAIL} = 1\right) \\ &+ \delta_{1k} 1\left(dis_{jk}^{CBD} < 10, dis_{jkt-1}^{RAIL} < 2\right) + \delta_{2k} 1\left(dis_{jk}^{CBD} > 10, dis_{jkt-1}^{RAIL} < 2\right) \quad , \\ &+ \beta_{1k} dis_{jk}^{CBD} + \beta_{2k} \left(dis_{jk}^{CBD}\right)^2 + \varepsilon_{jk}\end{aligned}$$

where j indexes census tracts and k indexes metropolitan areas. ΔD equals 1 if the tract went from being greater than two kilometers from the nearest rail line at time t-1, to less than two kilometers at time t. The dependent variable is the ten-year change in the fraction of commuters using public transit. The key parameters of interest are γ_{1k} and γ_{2k}. They measure the treatment effects of access to a new rail line on transit ridership within and beyond ten kilometers of the CBD in each metropolitan area. We include metropolitan area fixed effects in order to account for potentially different trends in fares, transit service quality, and road quality. In order to control for potentially differing trends in transit use in areas that were accessible to rail lines in the base year relative to areas not near any rail lines, we also control for city-level access to rail in the base year. Finally, we include a quadratic in distance to the CBD to account for the fact that employment decentralization may differentially influence transit use in different regions of each metropolitan area.[26] We only report the estimated treatment effects γ_{1k} and γ_{2k} in table 8.[27]

We estimate separate treatment effects for each city for each decade in which new rail transit infrastructure opened. For example, Atlanta experienced rail transit expansions in the 1970s, 1980s, and 1990s. Information on the timing of the opening of new rail lines from table 1 reveals the true number of years associated with each treatment. Table 8, panel B presents analogous results over twenty- and thirty-year differences. We perform these calculations in order to provide a sense of the adjustment time needed for individuals to fully change their commuting behavior in responses to new commuting options. The reported coefficients in panel B are coefficients on indicators that

26. We have specified the estimation equation such that our estimated coefficients are the same as would come from estimating the equation separately by city.

27. If transit is built in places where commuters have a high unobserved taste for it, OLS will overestimate the true treatment effect. In this case, the results reported in table 8 represent an upper bound on how much public transit use would increase if a random census tract received increased access to rail transit, conditional on observables. Including controls for household income, age, gender, and race changes the estimated treatment effects little.

equal one for tracts receiving access to a new rail line in the first decade of the difference. In addition to the controls in the ten-year difference estimation equation, these regressions also control for innovations in rail transit access in the second and third decades of the long differences.

Transit Use Estimation Results

We focus primarily on the results from specification 3 because it includes the widest array of control variables. However, table 8 shows that each empirical specification gives similar qualitative results. First we consider the ten-year difference results presented in the first panel of the table. Within ten kilometers of the CBD, Atlanta in the 1990s has the largest treatment effect at 3.4 percentage points. At least ten kilometers from the CBD, Washington, and Boston in the 1970s show the largest treatment effects at over 0.09, mirroring their relatively large city treatment effects of over 2 percentage points for the decade. While twelve of twenty-eight estimated suburban treatment effects exceed 0.02, just three of twenty-six nearer to the CBD do. We find no statistically significant evidence that new rail lines drew any new riders to transit in Buffalo, Miami, Sacramento, San Jose, or St. Louis.

The model presented earlier in this paper and inspection of the raw data presented in tables 6 and 7 indicate that one should expect to see larger treatment effects in the suburbs than near the city centers. Indeed, this prediction also proves true in the regression results. While only four of twenty-six city/decade combinations have statistically significant coefficients on new rail access near the CBD, thirteen of twenty-eight do on new rail access at least ten kilometers from the CBD. In fact, in seventeen of twenty-five cases the estimated suburban treatment effect is greater than the estimated city treatment effect, and in none of the remaining cases can we statistically reject that the two estimated coefficients differ.

Diminishing returns due to the location of new rail lines might suggest that infrastructure built later should have a smaller treatment effect than that built earlier. Conversely, a network effects argument would predict that later infrastructure might lead to larger ridership increases because such riders would be connected to more possible destinations. We find evidence of decreasing marginal returns to new rail investments for every city that had rail transit expansions in more than one decade except Portland and perhaps Atlanta.[28]

28. Though the estimated treatment effects for Atlanta in the 1970s are small, this may be due to the fact that commuters had less than one year to adjust to the existence of the new infrastructure, as it was completed in 1979.

Due to adjustment costs, ten years may be too short of a time interval to evaluate the full impact of rail transit expansions on public transit use.[29] Conversely, due to ongoing employment suburbanization, transit expansions oriented toward the CBD may have their greatest impact early on. Only Boston and San Jose saw greater treatment effects over time near the CBD while only Washington has slightly larger estimated treatment effects in the twenty- and thirty-year differences for the suburbs. Based on this evidence, it appears that less than ten years is ample time for the new commuting equilibria to be achieved in most cases.

Overall, we find that the rail systems in Boston and Washington have been the most successful at drawing new riders to transit. Boston has long-run estimated treatment effects of 0.07 near the center and 0.10 in the suburbs, while Washington shows effects of 0.03 and 0.11, respectively. We find treatment effects that are positive and statistically significant for all cities except Buffalo, Sacramento, San Jose, and St. Louis. The next section evaluates the extent to which the associated increased transit ridership translates into welfare gains and the implications of our estimates for cities considering construction of new rail systems.

Welfare Consequences and Policy Implications

There are several arguments that could potentially justify large public investments in public transit.[30] First, rail transit exhibits sharply increasing returns. Thus if potential ridership is high, it may be optimal to subsidize transit use to the point that the average social cost of commuting by public transit is less than the average social cost of driving.[31] Such an argument is only relevant for areas where rail can draw enough riders to reach a sufficiently large scale. Second, if public transit can draw people out of their cars, negative externalities associated with driving, such as pollution and congestion, will be reduced.[32] Though it would be more efficient to use a Pigouvian taxation mechanism to price these externalities directly, the logistics and political fea-

29. The difference between short- and long-run elasticities of transit use is a point emphasized by Voith (1997).

30. Small and Gomez-Ibáñez (1999).

31. Viton (1992) discusses various studies finding that rail transit provision exhibits small increasing returns to scale while bus transit exhibits constant or decreasing returns to scale. However, Viton (1980) finds that the largest U.S. rail systems exhibit decreasing returns.

32. Parry and Small (forthcoming).

sibility of doing so may make such direct taxation difficult. Finally, public transit empowers the poor and disabled to be more mobile and may be justified on redistributive grounds.

Welfare Consequences

In this section, we focus primarily on measuring the importance of two welfare margins. First, we evaluate the extent to which commute times decline in treated tracts and how much people value these lower commute times. Second, we evaluate whether the fraction of households who do not own vehicles increases in treated tracts.

One important component of the welfare benefits of new rail lines is likely to be the shorter commute times that they provide. Table 9 reports average one-way commute times in 1980 and 2000 by distance to the nearest rail line in 2000 and distance to the CBD.[33] The final column shows the implied difference-in-difference parameter associated with the change in commute time in treated areas relative to that in control areas. This number only gives a rough idea of how much rail lines have influenced commute times since modal shares also determine average commute time. The first panel shows that average one-way commute times in Boston rose 2.1 minutes more slowly in treated areas near the city center relative to control areas. In Washington, city areas near rail lines constructed since 1980 saw a 0.9 minute faster decline in commute times than other areas. Suburban areas of Atlanta near rail lines also saw one minute slower increases in average commute times than not near rail lines. The second panel shows that Buffalo, Sacramento, and St. Louis had the largest differences in their changes in suburban commute times, at least two minutes per trip. Only Dallas had a relative commute time difference in the city of over one minute.

In table 10 we attempt to quantify the aggregate time saved in each city for all new rail commuters between 1980 and 2000 and its associated dollar value.[34] The left column reports for each of the sixteen new-transit cities an estimate of the number of new rail commuters between 1980 and 2000 caused by the rail transit construction. This number is the count of rail commuters in 2000 in each city that lived at least two kilometers from any rail lines that

33. We choose 1980 as the base year because this is the first year in which the census asked about commute times.

34. We calculate dollar value by multiplying hours saved by personal wage and salary income. There is some evidence suggesting that people may value commuting time less than work time, which would make our estimates an upper bound on the private value of new rail lines.

Table 9. Commuting Time, by City[a]

Panel A. Transit expansion cities with infrastructure in 1980

	Distance to CBD	*Within 2 km of a rail line that existed in 1980*		*At least 2 km from a rail line that existed in 1980*				
				1980		*2000*		
		1980	*2000*	*< 2 km*	*> 2 km*	*< 2 km*	*> 2 km*	*DD*[b]
Atlanta	<10 km	28.1	25.1	23.0	26.6	22.0	24.7	−0.9
	>10 km	27.9	28.1	22.1	25.7	23.8	28.4	1.0
Boston	<10 km	24.2	25.3	24.0	23.2	25.4	26.7	2.1
	>10 km	24.7	26.4	22.7	22.5	25.0	25.7	0.9
Chicago	<10 km	28.4	28.9	28.9	29.2	31.1	31.8	0.4
	>10 km	30.8	32.0	28.7	28.2	29.0	28.2	−0.3
San Francisco	<10 km	26.1	27.2	18.2	24.5	21.5	27.2	−0.6
	>10 km	24.6	27.1	24.4	24.9	27.0	27.2	−0.3
Washington	<10 km	27.1	25.5	28.8	28.3	27.5	27.9	0.9
	>10 km	28.9	31.3	26.0	29.3	27.4	30.6	−0.1

Panel B. Cities with all rail transit built since 1980

	Distance to CBD	*1980*		*2000*		
		< 2 km	*> 2 km*	*< 2 km*	*> 2 km*	*DD*[b]
Baltimore	<10 km	27.5	26.7	26.5	26.0	0.3
	>10 km	23.2	26.2	23.5	26.3	−0.2
Buffalo	<10 km	19.5	19.5	17.5	17.4	−0.1
	>10 km	18.7	19.5	14.3	18.7	3.6
Dallas	<10 km	23.9	23.7	22.1	23.3	1.4
	>10 km	22.6	22.9	25.2	24.0	−1.5
Denver[c]	<10 km	19.5	20.4	20.3	21.2	0.0
	>10 km	. . .	23.0	. . .	23.5	. . .
Los Angeles	<10 km	25.9	25.5	28.5	26.6	−1.5
	>10 km	24.1	23.8	25.3	25.1	0.1
Miami	<10 km	24.1	22.6	24.3	23.0	0.2
	>10 km	21.2	24.1	23.5	27.0	0.6
Portland	<10 km	18.4	20.5	18.2	19.7	−0.6
	>10 km	20.9	22.2	22.2	22.0	−1.5
Sacramento	<10 km	16.7	17.5	17.7	19.4	0.9
	>10 km	19.7	20.6	19.4	23.6	3.3
San Diego	<10 km	18.0	17.6	19.1	19.5	0.8
	>10 km	20.9	21.2	22.8	21.8	−1.3
San Jose	<10 km	23.2	22.9	23.1	22.4	−0.4
	>10 km	22.2	23.4	22.6	24.6	0.8
St. Louis	<10 km	21.3	22.9	21.0	21.6	−1.0
	>10 km	22.2	22.5	19.4	21.7	2.0

Source: Authors' calculations.

a. Each entry is average commuting time to work (one way) in minutes given the rail transit infrastructure that existed in 2000. Sample includes all tracts within forty kilometers of the central business district.

b. Implied difference-in-difference parameter.

c. Denver had no rail transit infrastructure at least ten kilometers from the CBD in 2000.

Table 10. Estimated Time Savings Due to Rail Transit Construction, 1980–2000[a]

	Number of new rail commuters 1980–2000[b]	*Aggregate hours saved per day* / *Aggregate dollar value per day*[c] 1	2	3	4
Atlanta	19,351	. . .	31,100	. . .	17,681
		. . .	624,438	. . .	352,697
Baltimore	11,746	3,450	7,495	3,126	3,718
		61,921	142,002	56,313	67,334
Boston	20,406	. . .	941	. . .	0
		. . .	20,218	. . .	0
Buffalo	1,358	1,933	1,446	1,540	943
		30,909	21,841	25,292	14,678
Chicago	23,943	. . .	14,961	. . .	14,942
		. . .	270,416	. . .	270,070
Dallas[d]	1,921	2,534	2,338	2,534	2,338
		50,470	45,786	50,470	45,786
Denver[d]	533	379	822	379	822
		6,491	14,027	6,491	14,027
Los Angeles	8,064	4,871	6,533	2,419	3,024
		80,750	106,715	44,835	54,157
Miami	6,234	2,341	3,216	1,866	3,216
		41,707	55,964	33,112	55,964
Portland	6,990	2,469	4,045	399	504
		43,033	70,216	6,982	8,811
Sacramento	2,521	2,183	3,628	1,111	3,408
		39,617	61,286	18,688	56,633
San Diego	2,229	111	122	278	258
		1,578	1,724	3,936	3,649
San Francisco	13,226	. . .	7,284	. . .	1,368
		. . .	183,646	. . .	33,041
San Jose	4,503	0	0	0	0
		0	0	0	0
St. Louis	2,722	7,420	6,363	2,379	2,789
		133,061	104,954	38,501	44,767
Washington	107,788	. . .	132,591	. . .	63,698
		. . .	3,124,964	. . .	1,497,616

Source: Authors' calculations.

a. Columns 1 and 2 use modal shares in 1980 for the same region to assign rail commuters, while columns 3 and 4 use ten-year difference coefficients reported in table 8, panel A, for the decade in which the largest rail expansion occurred in each city.

Estimates in columns 1 and 3 use estimated bus and car commuting times from 1980, while those in columns 2 and 4 use estimated bus and car commuting times from 2000. Estimated rail commuting times are from 2000 only. Estimated commuting times are calculated separately for concentric rings around each central business district based on regressions of aggregate travel time on the number of commuters by mode. Certain entries are missing because of data limitations in estimating commuting time by mode in 1980.

b. Number of new riders is calculated based on census counts of the number of people who lived in census tracts at least 2 kilometers away from the nearest rail line in 1980 commuting by rail transit in 2000.

c. Estimates of hours saved are calculated as follows: Based on the number of rail commuters in the first column, we impute how many people would have commuted by car and bus if the rail infrastructure were as it was in 1980. We multiply the number in each group by the time difference associated with commuting by rail over their imputed commuting mode were rail to not exist.

d. Some estimates for Dallas and Denver are identical because both procedures allocate all rail users in 2000 at each distance from the CBD to commute by the same mode absent the rail infrastructure.

existed in 1980. Each commuter's time savings from substituting to rail transit depend on where he or she lives and works within the metropolitan area. We estimate census tract level regressions of aggregate commute time as a function of the number of commuters using each of four commuting modes (rail, bus, car, and by foot) for each ring 2.5 kilometers wide around each metropolitan area's CBD. These regressions allow us to estimate the marginal change in a worker's commute time if he commuted by rail instead of by bus or car for each ring in each city. Estimates of hours saved are calculated by taking the number of rail commuters in the first column of table 10, imputing how many would be bus and car commuters if the rail infrastructure looked like it did in 1980, and multiplying each group by the time difference associated with commuting by rail over their imputed commuting mode were rail to not exist. We set all negative estimated rail commuting time premiums to zero. We also calculate a ring-specific average wage rate to value these commuters' time. Estimates 1 and 2 in table 10 allocate the 2000 rail users to bus and car based on 1980 modal shares in the same CBD ring while estimates 3 and 4 use coefficients for the same region from table 8, panel A for the decade in which the largest infrastructure expansion took place. Estimates 1 and 3 apply car and bus commute times from the 1980 commuting time regressions while estimates 2 and 4 use modal commute time estimates from the 2000 regressions. Missing entries occur because for some areas we could not estimate separate bus and rail commute times in 1980.[35]

Washington has by far the largest estimated daily time value associated with its new rail transit infrastructure at over 50,000 commuting hours saved per work day. Atlanta comes in second and Chicago, third, as the only other cities with over 10,000 hours estimated to be saved per day. Note that while Chicago in particular had declining transit usage, there were still large aggregate welfare gains associated with commuters substituting from buses to faster rail lines. This comes largely from the fact that Chicago is relatively densely populated and still has a high level of transit usage. Cities with smaller scale light rail systems such as Dallas, Los Angeles, Sacramento, and St. Louis also show some large welfare gains associated with their rail systems, with over 2,000 aggregate commuting hours estimated to be saved per day. However, the lower population densities in these cities and the lower speeds of light rail versus heavy rail limit the market size and time saved per person available. The dollar values of saved aggregate commuting times are

35. For 1980 we do not have a breakdown of transit commuters into bus and rail. Thus in cities with rail lines in 1980 it is difficult to separate bus from rail commuting times.

largely commensurate with time saved. Among all cities, Washington stands out as having a very large estimated value of its subway system of well over $1 million per day.

A second potential welfare gain from rail transit expansion is that vehicle ownership and use may decline. Local externalities such as urban road congestion and air pollution are exacerbated by increased vehicle use. While the census does not report information on how much people drive, it does report what share of households within each census tract does not own a vehicle. Using data from 1980 to 2000, we regress the share of households that do not own a vehicle on a dummy variable that equals one if the tract is within two kilometers of rail transit. Controlling for metropolitan area fixed effects, year dummies, tract income, and the tract's distance from the CBD, we find that that the share of households that do not own a vehicle is 0.054 higher in tracts close to transit relative to observationally identical tracts far from transit. Given that the average share of households that do not own a car is 0.135, this differential is large. However, when we run a regression with tract fixed effects, we find no evidence that treated tracts experience reductions in vehicle ownership rates relative to control tracts. Furthermore, we find little evidence of trend breaks in pollution or congestion levels after the construction of new rail transit infrastructure. This mixed evidence suggests that future research should use microdata to examine the joint household decision of location choice and durables purchases as cities invest in changing the supply of local public goods (that is, rail transit access).

As mentioned above, public transit expansions may also improve inner city residents' employment prospects.[36] Rail transit expansions offer a potential natural experiment for testing whether inner-city unemployment rates decline as public transit access to CBD jobs improves.[37] Due to data limitations (namely that zip code level employment data before 1994 does not exist), we are unable to test whether employer location decisions are affected by the location of rail transit. In addition, any study of local unemployment dynamics would have to grapple with the reverse causality issue that public transit access

36. Ihlanfeldt and Sjoquist (1990) find significant effects of access on employment of black teenagers. However, Ellwood (1986), Wilson (1987), and others argue that characteristics of inner-city residents are more important in determining their job prospects than the extent to which transit connects them to employment centers. See Kain (1992) for a survey of the spatial mismatch literature.

37. Holzer, Quigley, and Raphael (2003) show that after BART made suburban jobs more accessible outside San Francisco, suburban employers near a new rail station hired significantly more Hispanics.

often acts as a poverty magnet.[38] If the poor are attracted to living close to public transit, then this would bias OLS results of a regression of tract-level unemployment on tract access to public transit toward finding no beneficial effects of rail transit access on mitigating urban minority unemployment.

A related important potential welfare gain associated with rail transit improvements is the improved transportation options for nonworkers. The core of our analysis has focused on commuters. However, teenagers, the elderly, and tourists represent a large number of transit trips in many major U.S. cities. If the future of downtowns is as "consumer cities," high-quality public transit could be a complement to downtown amenities such as restaurants and culture.[39] As urban crime rates decline,[40] middle-class households may be more willing to use this commuting option to get downtown. As the baby boomers age, and given the share of the elderly who head their own households, this demographic shift may increase the demand for public transit.

As was discussed above, the construction costs of new rail infrastructure vary considerably by city. This section has shown that the benefits also vary. While we find scant evidence that rail lines have reduced pollution and congestion externalities, we do find potentially large commuting time savings associated with new rail infrastructure. There are two models that cities have used in building rail systems, both of which may make sense depending on city structure. They can invest a lot of money in faster heavy rail infrastructure as was done in Washington, Atlanta, and Chicago. Though such a strategy has high costs, it also has larger potential benefits. The second strategy is more like that undertaken in Dallas, Sacramento, and San Diego. These cities built low-cost systems that largely make use of existing railroad rights of way. The downside is that they serve fewer people and do not provide service that is as fast or convenient as heavy rail. Ultimately, the structure of the metropolitan area will determine what the optimal nature of the rail infrastructure is, if there should be any at all. We now turn to the details surrounding this choice.

Policy Implications

How do our results documenting rail transit trends over the last thirty years inform public policy decisions being made today? A common refrain among leading transportation scholars is that we overinvest in rail relative to buses.

38. Glaeser, Kahn, and Rappaport (2000).
39. Glaeser, Kolko, and Saiz (2001).
40. Levitt (2004).

Larger increases in transit ridership could have been achieved if transit operators had spent a larger fraction of available revenues on bus system improvements rather than on costly and ineffective rail systems.[41] As employment continues to migrate to the suburbs and wages rise, public transit investment targeted toward connecting suburban areas with the central business district faces a serious challenge in generating a large market share. We are most optimistic about the prospects for rail transit investment in cities with a significant employment share downtown and where the rail's speed allows it to be a competitive alternative for the automobile.

Several cities have undertaken construction of new rail systems since 2000. For example, Phoenix is building a light rail system that is planned to open in December 2008. Rail transit proponents have sketched optimistic visions of the role new rail lines can play in improving the quality of life in Phoenix.

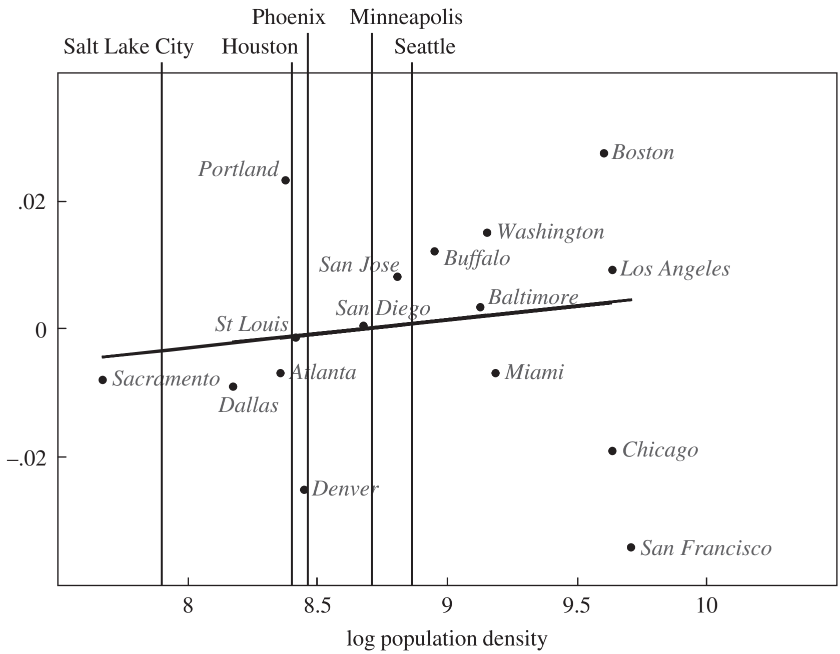
> "When that happens, transportation officials say congestion will be greatly eased on the freeways that serve about 3 million residents in one of the nation's fastest-growing cities. Cars line up for blocks at some freeway on-ramps during peak hours, and it can easily take more than an hour for motorists to get to the outskirts from downtown during rush hour. With light rail, it will take about twenty minutes to get from downtown to Tempe and about the same time to get to north Phoenix. . . . Besides easing traffic problems, Phoenix Mayor Phil Gordon said light rail will create 1,600 full-time jobs. Property values surrounding the tract will increase and the air will be cleaner," he added."[42]

What does one learn about the likely success of new rail transit investments from the patterns we have reported for the sixteen major metropolitan areas that have invested in rail transit between 1970 and 2000? Figures 5 and 6 present graphs of the ten-year difference coefficients associated with the decade that had the largest increase in rail transit infrastructure in each city as a function of population density in the base year. Estimated treatment effects for areas both within and beyond ten kilometers of the CBD have a positive relationship with the log population density. Second-stage regressions of these coefficients on log population density imply responses of

41. Kain (1999, p. 396).

42. "Project opponent Camilla Strongin said transportation money would be better spent on freeways since light rail is expensive and construction will clog surface streets even more. 'The city is not designed with a dense population core that would be well served by a light rail system.' In 2000 Phoenix passed a 0.4 percent sales tax for a transit plan that included light rail. The initial twenty-mile arterial route will cost $1.3 billion, about half of which comes from the federal government." Ananda Shorey, "Arizona's Light Rail System Hailed," *Associated Press,* January 25, 2005.

Figure 5. Estimated Treatment Effects within Ten Kilometers of CBD as a Function of Population Density

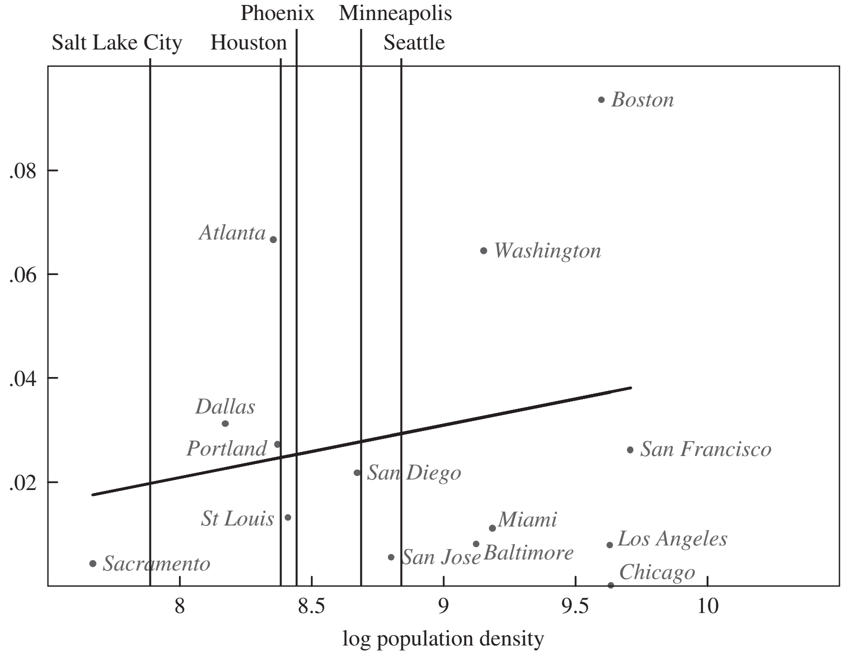


Source: Authors' calculations using results in table 8 and census tract data from 2000.

about 0.5 and 1 percentage points near and far from the CBD, respectively, to a doubling in population density.[43] Superimposed on the graphs in figures 5 and 6 are lines indicating population densities in five metropolitan areas that have embarked on rail transit construction projects since 2000: Salt Lake City, Houston, Phoenix, Minneapolis, and Seattle. Our cursory analy-

43. One notable outlier in many of our results is Chicago. Cox and Love (1998) note that bus ridership in Chicago plummeted between 1979 and 1994 by almost one-third, while rail ridership held steady despite several major expansions in the rail network. They cite sharply rising fares as an important explanation for these trends. Our largest estimated treatment effect for Chicago is in the 1970s, before most of the fare hikes. Furthermore, our thirty-year difference regression potentially suffers from a bias associated with the closing of the entire Green Line from 1994 to 1996 for reconstruction and a series of funding crises that precipitated a host of service revisions. Because of these peculiarities, we exclude Chicago from the second-stage regressions.

Figure 6. Estimated Treatment Effects at Least Ten Kilometers from CBD as a Function of Population Density



Source: Authors' calculations using results in table 8 and census tract data from 2000.

sis indicates that Phoenix's new light rail line should not draw many commuters out of their cars.[44]

Despite the pessimistic evidence we have presented about the likely success of new rail lines, they are being built at historically high rates. Why is this? An important reason is that most of the cost is covered by the federal government. The nature of federal funding formulas is such that they fund capital intensive transit projects like fixed rail over other types of projects that might actually draw more new riders. The heavy subsidy from the federal government no doubt sufficiently shifts the local funding calculus such that

44. In 2000, 6.5 percent of commuters living within twenty-five miles of the Phoenix CBD commuted by bus. Thus aggregate commuting time savings from the new rail line are also likely to be low. With almost 20 percent of Seattle commuters using the bus in 2000, out of all cities building rail lines since 2000 Seattle seems to be the one where rail is most likely to be successful.

from a local perspective many of these cities are acting optimally by building these new rail lines.

Our empirical work suggests that there are distributional consequences from expanding rail transit infrastructure. Suburban workers who commute by car are likely to gain little from improved transit, while bus commuters who work in the CBD enjoy large time savings in many cities. Since bus riders tend to be poorer people, this suggests that rail transit expansions are progressive. This is a contentious point that merits future research. Transportation scholars have argued that an unintended consequence of rail transit expansion is bus coverage deterioration due to budget reallocations to pay for the new transit lines.[45] If this is true and if the poor are more likely to take the bus than rail transit, then transit expansion could be regressive public policy.[46]

A final policy issue worth noting is the choice of product quality. In this paper, we have not attempted to measure differential rail transit quality by city.[47] For example, some cities may have rail transit that runs more frequently or that features more policing. As per-capita incomes rise, and assuming that amenities are normal goods, public transit will be more successful in luring the middle class and wealthy if the ride itself is a pleasant experience. Such quality is costly to provide. Future research might investigate how different cities make quantity/quality trade-offs concerning their rail transit expansions.

Conclusions

Sixteen major U.S. cities have built or expanded rail transit networks over the past thirty years. These cities spent large sums of money, in some cases

45. Kain (1990 and 1997).

46. "[Bus riders in Los Angeles in late 1994 filed a law] suit against the Metropolitan Transportation Authority (MTA), alleging that MTA's transportation policies discriminated against minorities in violation of the Civil Rights Act of 1964 and the Fourteenth Amendment to the United States Constitution. MTA is the statutorily created regional transportation planning, construction, funding, and operating agency for Los Angeles County. The suit alleged that MTA was spending a disproportionately large portion of its budget on rail lines and suburban bus systems that would primarily benefit white suburban commuters, while intentionally neglecting inner-city and transit-dependent minority bus riders who relied on the city bus system. The lawsuit was triggered by the MTA's decision to spend several hundred million dollars on a new rail line, forgoing an opportunity to reduce overcrowding problems on city buses, while at the same time increasing bus fares and eliminating monthly discount passes." *Labor/Community Strategy* v. *Los Angeles County Metropolitan Transit Authority* 99-56581 (9th Cir. 2001).

47. We have included city level fixed effects to capture cross-city differences in rail quality that are uniform at a point in time. However, our regressions do not capture any within city variation in the quality and speed of rail transit.

billions of dollars, with a common goal of increasing transit ridership. At the same time, transit ridership overall has fallen as residences and employment have suburbanized, real incomes have risen and cars have gotten less expensive. We provide new evidence that informs evaluation of whether the huge costs associated with building and operating new rail transit lines is justified.

Many past studies of transit use have relied on aggregate data over time for one or a few metropolitan areas. In contrast, we exploit detailed geocoded data for the universe of cities that expanded their rail networks between 1970 and 2000 to garner estimates of the extent to which new rail lines induce commuters to leave their cars and to evaluate the associated welfare gains. A simple model predicts that the greatest increase in public transit use as a result of a new rail commuting option occurs further from the CBD in areas where people commute to the CBD primarily by car. Because of higher population density, a new rail line will draw more new riders close to the CBD, but most of these are likely to be former bus users. Bus to rail substitution does not increase an area's share of public transit commuters, but it may still represent large welfare gains from reduced commute times.

Our empirical work confirms these predictions. While we find few cities where new rail transit lines drew many new transit riders living near the CDB, we find significant effects far from the CBD in ten of the sixteen cities we investigate. Consistent with the conventional wisdom, we also find that, overall, new rail lines have been more successful at drawing new riders in denser, more centralized cities. Washington and Boston are standouts in which new rail lines have been relatively successful at luring commuters out of their cars. In contrast to the pollution and congestion reductions touted by many rail transit proponents, we argue that the primary social benefit associated with new rail lines is that they may significantly reduce trip times. Given that the majority of rail transit riders are former bus users, mode switching to rail has the potential to represent large aggregate time savings. Once again, Washington in particular stands out as a city in which commuters are significantly better off as a result of having the option of using rail transit. While there are measurable welfare benefits of new rail lines in other rail transit cities, they appear to be much smaller.

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