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The effects of new public projects to expand urban rail transit

Nathaniel Baum-Snow[a], Matthew E. Kahn[b,*]

[a]Federal Reserve Bank of New York, 33 Liberty Street, New York, NY 10045, USA
[b]Columbia University, Department of Economics and International Affairs, 420 W. 118th Street, New York, NY 10027, USA

Abstract

Many US cities invest in large public transit projects in order to reduce private vehicle dependence and to reverse the downward trend in public transit use. Using a unique panel data set for five major cities that upgraded their rail transit systems in the 1980s, we estimate new rail transit's impact on usage and housing values, using distance as a proxy for transit access. New rail transit has a small impact on usage and housing values. This impact is enough to represent tangible benefits of new transit to nearby residents. New transit's benefits are not uniformly distributed. We document which demographic groups are over represented in transit growth areas and the changes in transit usage by different demographic groups.

Keywords: Public transit; Usage; Housing values

1. Introduction

Public transit use has been declining for decades. Between 1940 and 1990, the number of trips made using public transit in the United States fell from over 13 to under 9 billion, as the population more than doubled (O'Sullivan, 1996). In tandem with this decline in transit usage, private vehicle usage has continued to rise. Between 1975 and 1990, the civilian population grew by 15.9% while total vehicle miles traveled in passenger cars grew by 43.6% (Downs, 1992). Commut-

*Corresponding author.
E-mail address: mk214@columbia.edu (M.E. Kahn)

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ing by private vehicle continues to grow in popularity due to growing household incomes, suburbanization of population and employment, the rising quality of private vehicles and the declining price of gasoline.

While urban public transit usage is down, more cities are investing in improving and building new rail transit systems (Lave, 1970). Los Angeles is expected to spend $5.9 billion, or $300 million per mile for its new Red Line subway. Portland has spent approximately $40 million per mile to build its surface light rail line. Denver, Dallas, Baltimore, St. Louis and San Diego have all spent between $10 and $40 million per mile for their light rail systems, depending on the need for land seizure by eminent domain, tunneling, single/double tracking, and the extent to which the rail line is grade separated from roadways (Richmond, 1998).

Increased supply in the face of falling demand may appear puzzling. While such transit projects are costly, much of the cost is borne by the federal government. The local share of operating expenses range from 15 to 50% for most major transit systems (National Urban Mass Transportation Statistics, 1989). The local share of capital improvement expenses was an average of 20% in 1989.

If the introduction of improved public transit induces people to switch from driving to transit, local air pollution would be lower, vehicle congestion would be reduced, and the transportation sector would make a smaller contribution toward Greenhouse gases (Small and Kazimi, 1995). Though local air quality has improved sharply over the last 25 years due to Clean Air Act regulations, congestion is a growing urban problem (Downs, 1992; Glaeser, 1998; Small and Gomez-Ibáñez, 1999). In addition, better transit may disproportionately improve the quality of life and the quality of job opportunities for the urban poor. Public transit potentially increases the access of the poor to better labor market opportunities (Kain, 1968). This comes in addition to reduced commuting times for people served by better transit.

Transit authorities are optimistic that these potential benefits to new transit are indeed large; hence, the large recent investments in public transit infrastructure (Cervero, 1998). Researchers, however, have seriously questioned the cost/benefit modeling which lies behind the decision to push forward with costly irreversible transit projects. While there is evidence that new rail transit is sometimes capitalized into housing values, indicating the existence of some public benefit, the costs to build and maintain new transit are far higher than these measured benefits. There is also evidence that ex-ante overly optimistic forecasts of usage and cost are common (Kain, 1991; Pickrell, 1992; Kain, 1993; Gomez-Ibáñez, 1996; Kain, 1997a).

This paper uses a unique panel data set to evaluate the effects of recent rail transit expansions. We measure the extent to which new rail transit induces commuter mode switching toward transit, which demographic groups gain the most from rail improvements, and how rental and home prices are affected by transit.

We study these effects of new rail transit by examining 'before' and 'after' data for census tracts in five cities which upgraded rail transit between 1980 and 1990. The distance from each census tract within a 25-km radius of the central business district to the nearest rail transit line in 1980 and 1990 is a key variable in this analysis (Voith, 1998). As new transit is built between 1980 and 1990, a tract's distance from transit changes, affecting ridership and housing values.

We exploit the variation in transit access changes among census tracts within five cities to evaluate the effects of transit expansions. Extending transit lines makes public transit more accessible and reduces the time cost of commuting by public transit. Commuters who live in census tracts now closer to public transit have a greater incentive to use it. Public transit use in such areas may rise both due to incumbent mode switching and due to population sorting. As transit access improves, public transit users have a greater variety of communities to choose among.

Tract level variation in proximity to public transit allows us to estimate richer econometric models than can be estimated using aggregate city level annual data. Our study complements aggregate transport studies which explain year to year variation in city transit ridership using macro variables such as annual average income growth and changes in gas prices (for example, see Kain, 1997b; Voith, 1997).

This paper finds that rail transit improvements lead to increased mass transit use for commutation. Part of this increase is attributable to new migrants to these tracts having higher probabilities of using public transit than tract incumbents. Transit improvements also lead to a small but significant amount of mode switching toward public transit. Because the majority of transit improvements studied here go into the suburbs, we find that the greatest beneficiaries have been non-blacks and people over age 35. In addition, we find that proximity to rail transit is capitalized into home prices and rents.

2. Transit upgrades in five metropolitan areas

Five US cities were chosen for the analysis. Boston, Atlanta, Chicago, Portland, and Washington DC were the only five large American metropolitan areas with discrete rail transit improvements during the 1980s.[1] The use of five cities for analysis allows us to generalize results beyond just one metropolitan area to better

[1] New transit lines or segments in these cities opened between the end of 1979 and 1988. There was no incremental opening of tract segments during the census taking period in 1979 or 1989, thus there is no question that the 'treatment' of adding new transit access occurred between the two censuses, with ample time to allow individuals to alter their commuting behavior before being evaluated by the 1990 census.

make a judgement on the effects of transit expansions in general.[2] The five case cities also happen to represent various regions of the country and types of transit networks. Boston and Chicago represent old cities with networks that have continually operated for over 80 years and are currently in the process of renewal and expansion. Because of their highly centralized and relatively dense structure, these two cities may be among the best candidates for viable mass transit. Atlanta and Washington have new comprehensive heavy rail systems. Despite the lack of rail transit until the 1970s, both of these cities had relatively high transit usage when compared to the average US metropolitan area. Finally, Portland's light rail line represents the newly popular incremental approach to the establishment of a rail transit network.[3] At $40 million per mile, the construction of Portland's MAX light rail line was by far the least expensive per mile.

The goals of the five transit improvement projects differed by city. While the Boston expansion was built to serve the terminus of a major commuter highway and Chicago's is designed to serve O'Hare airport, Atlanta, Washington and Portland's improvements were designed to serve a much wider constituency. One important stated goal of each of the new systems was to entice commuters out of their cars and decrease road congestion substantially throughout the city. The smaller scope of the Boston and Chicago projects meant that a much smaller target for congestion easing was stated.

3. Measuring new transit's impact

Areas served directly by new urban rail lines have seen greatly reduced transit commute times to the CBD. Public transit usage can rise in such areas because commuters substitute to public transit away from private vehicles or if new migrants to the community are more likely to use public transit than the residents who moved out. Our empirical work aims to quantify both effects.

A cost minimizing commuter may switch from private vehicle to rail if increased access significantly reduces total travel costs. An individual minimizes her commuting cost by evaluating various commuting options. Walking to public transit requires time spent walking to the rail line, waiting for the train and riding the train. Driving to work requires owning a car, paying for gas and parking and

[2] Though several other cities expanded their transit networks during the 1980s as well, notably Los Angeles, San Diego and Baltimore, their expansions were sufficiently incremental such that it is hard to evaluate for the purposes of analysis where one decade ended and the next began.

[3] Now that the initial portion of Portland's MAX light rail line has been declared a success by transit advocates in Portland, the line is being extended through the western suburbs, eventually to the airport. Washington and Atlanta planned their systems more as a unit to be built at once, whereas Portland is building incrementally.

time spent driving. Increases in gas prices, parking fees or road congestion provide an incentive to substitute to public transit.

Improvement in the rail transit system may cause a reduction in the transit riding time, a reduction in the time it takes to get from home to the transit service, and/or the time it takes to walk from transit to work. It is not enough for new transit to reduce a commuter's potential transit commuting time; it must reduce it enough to make it cheaper than driving. Transit is bound to be more successful in denser cities where driving time will be longer due to congestion and walking/driving time to and from transit will be shorter because home and work are likely to be closer to transit than in less dense cities.

A simple calculation demonstrates the potential incentives from new rail transit. We define potential walk and riders to be those individuals who live within 2 km of a transit line. Between 1980 and 1990, transit upgrades led to over two million more households living within 2 km of transit in our five case cities combined. How large could the incentive for them to switch to transit be? Suppose that a rail line is built such that a walker becomes 2 km closer to transit. Walking 4 km an hour, this commuter saves 1 h a day or 250 h per year. At a wage of $15 an hour, the time price of public commuting has just fallen by $1237.50, assuming a conservative time–cost of commuting estimate of 33% of the hourly wage. If it saves park and riders 15 min a day, the incentive for them would be $310.[4] Since the commuter drives to the public transit station, reductions in distance between one's residence and the public transit station do not have as great an impact on time savings.[5]

A geographic area's average public transit use can rise as access to public transit increases if the local amenity improvement triggers Tiebout migration. Before the transit upgrade, relatively few locations had access to transit. If there are a significant number of public transit riders (because they work where the rail goes), then home prices would be higher than average near transit. Transit expansions create an opportunity for mobile households who use public transit to move to areas where access has improved.[6] It is therefore possible that average public transit use could rise in communities where access has increased while aggregate public transit use does not change.

Rail transit construction could reduce the use of other public transport modes.

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[4]See Waters (1995) and Calfee and Winston (1998) for a discussion of various estimates of the time–cost of commuting.

[5]Lack of parking at places of employment and transit stations will affect transit ridership. Arnott and MacKinnon (1977) present a general equilibrium model of how locational choice and commuting patterns are affected by changes in parking. Merriman (1998) demonstrates that lack of parking at Chicago commuter rail stations limits ridership, and that ridership increases when parking is expanded. For park and riders, who make up a considerable percentage of potential new transit riders, transit station parking availability will affect behavior.

[6]Non-transit users would be increasingly likely to sell their homes in now accessible public transit areas to commuters who value this local public good.

Table 1
Trends in bus service[a]

	Number of buses during maximum service	
	1980	1989
Atlanta	658	566
Boston	842	839
Chicago	2121	1803
Portland	473	420
Washington	1545	1400

[a] Source: National Urban Mass Transportation Statistics (1982, 1989).

An unintended consequence of improved rail coverage is that bus service may be scaled back. Bus lines are often reoriented in new rail cities from serving the CBD directly to serving as feeders to rail lines. A look at digital maps of bus routes in the 1990s reveals that the effect on bus service of new rail lines, though significant, is not huge, and new rail service did not decrease any of these five transit systems' geographic coverage (see Table 1).[7]

4. Data sets

To study the impact of rail construction on worker commuting patterns, household access and home prices, this paper uses 1980 and 1990 Census of Population and Housing tract level data and micro data from the 1% PUMS. Tract-level data for 1980 and 1990 are taken from the Census of Population and Housing file stf3a. These files include information on what share of a census tract's commuters use public transit and provides tract level means of demographic and housing attributes. Using the 1980 and 1990 Census micro data, we construct a sample of working heads of household ages twenty and up. Public transport is coded as a dummy which equals one if person reports to commute by bus or trolley bus, streetcar or trolley car, subway or elevated, railroad or ferryboat. Additional variables used include dummy variables for sex, race, age, living in the central city and household income. All demographic summary statistics are available on request.

[7] The number of buses used in peak periods and the expenditure on bus service only dropped approximately 10% in the five case cities during the 1980s, while rail service increased dramatically in some areas. In 1990, the average distance of tracts to any bus line was 0.6 km, while it was 2.7 km to a bus that ran directly to the center city. These numbers rise to 1.1 and 4.4 km, respectively for those tracts farther than 2 km from a rail line in 1990. These figures show that even after rail was introduced, reasonable access to bus service, even direct bus service to the CBD, was for the most part still available.

This paper's major data innovation is to create a measure of each census tract's proximity to rail transit in 1980 and 1990. The spatial component was built using digital maps of census tracts and transit lines. The spatial coverages, or digital maps, of the transit system for each of the five cities were taken from the national transit coverage of the 1996 National Transportation Atlas Database. It is approximately at the 1:100 000 scale. This means that the maps from which the digitized data was scanned in had 1 mm represent 100 m. The census tract coverages came from the Census Tiger Database. Tracts for each of the counties included in the five MSAs were extracted separately and merged together to form one coverage for each MSA. The tract centroids were calculated using a script that comes as part of the Arcview software package.

The transit coverages for 1980 and 1990 were constructed using separate transit histories taken from various places off of the Internet for each of the five transit systems studied. Those cities without systems in 1980 (Portland and Atlanta) had transit access measured from the center of downtown. This was a point that was chosen based on the central business district, and was near to what was to be in 1990 the central portion of the transit system. The transit access variables, built using Arcview, were merged into the 1990 data set (because this is the year for which the Arcview census tract codes matched) and then converted back to 1980 tracts with the rest of the 1990 data using population weighted conversion factors. This procedure yields for each census tract its distance to the nearest transit line in 1980 and 1990. We assume that given the existence of a transit line, surrounding residential communities are given adequate access to this line through stations.[8]

We recognize that changes in distance to rail is an imperfect measure of improvements in public transit quality but this measure captures that different communities within the same city are differentially affected by transit changes. Distance proxies for the time cost of using public transit. Congestion and auto pollution are also increasing functions of household distance from public transit. Workers who commute by walking to a station and then taking public transit impose the smallest congestion and pollution externalities.

Table 2 uses the 1980 and 1990 census tract data sets to present some facts on how public transit use and access to transit changed in each city between 1980 and 1990. For the five-city sample, the population-weighted percent of workers commuting by public transit fell from 21% to 20% between 1980 and 1990. Portland had the lowest public transit use while Chicago had the highest. Overall transit use fell slightly in each city over the decade.

In 1980 the average tract for the five-city sample was 4.76 km from transit. In

[8]This is not an unfair assumption. Planners are likely to ensure that transit lines serve the maximum number of people possible along them. In Atlanta, the correlation between tract distance to transit line and transit station in 1990 is 0.9578.

Table 2
Public transit access upgrades between 1980 and 1990[a]

	Census tract count		Average transit distance (km)		Average share using transit to get to work (Total)		Average share using transit to get to work (walk and ride)	
	Total	New walk and ride	1980	1990	1980	1990	1980	1990
Five city average	3586	514	5.79 (5.87)	3.67 (3.96)	0.21 (0.14)	0.20 (0.14)	0.21 (0.13)	0.20 (0.13)
Atlanta	411	234	11.9 (7.1)	3.29 (3.26)	0.16 (0.14)	0.14 (0.13)	0.22 (0.13)	0.19 (0.13)
Boston	488	18	3.86 (4.11)	3.65 (4.09)	0.20 (0.13)	0.19 (0.12)	0.24 (0.05)	0.23 (0.07)
Chicago	1252	16	3.07 (3.29)	2.61 (2.94)	0.28 (0.14)	0.27 (0.14)	0.16 (0.05)	0.14 (0.04)
Portland	322	81	10.52 (6.33)	5.90 (5.46)	0.12 (0.06)	0.09 (0.06)	0.14 (0.06)	0.11 (0.06)
Washington	1113	165	6.20 (5.48)	4.44 (4.26)	0.19 (0.14)	0.18 (0.14)	0.23 (0.16)	0.27 (0.14)

[a] Notes: Values determined based on observations without missing values for any of the variables in Table 3 regressions. All values are population-weighted means. Standard deviations are listed below means. New walk and ride tracts are defined as those that moved from farther than 2 km to closer than 2 km away from rail transit between 1980 and 1990.

1990, the average tract from the same set was 3.11 km away. This 1.65-km reduction in distance masks wide heterogeneity across and within the cities. The average distance fell by over 7 km for the average Atlanta tract between 1980 and 1990 while it fell by only 0.18 km in Boston and less than 0.15 km in Chicago. Since Boston and Chicago had only very localized expansions, their average decreases in distance to transit were small, while Atlanta's MARTA system is extensive and opened in its entirety during the 1980s (Bollinger and Ihlanfeldt, 1997). The greatest within city transit access convergence took place in Atlanta and Portland relative to Boston, Washington or Chicago.

Because people who live near enough to transit to walk to it are the greatest potential market for new transit, we break out ridership in walk and ride tracts separately. Even in tracts that moved closer to transit over the decade, population-weighted transit use declined in all five cities except Washington, though from much higher initial levels. As we will argue later, this is likely due to the rapid suburbanization of jobs and perhaps the changing demographic attributes of many new transit areas.

5. Regression specifications

5.1. Transit use

To study whether transit improvements stimulate usage, we present regressions in which the unit of observation is the census tract. Using 1980 and 1990 census tract data, we estimate a multivariate regression of the percent of commuters who use public transit to get to work as a function of tract demographic variables and the tract's distance from public transit. This levels regression for tract i in city j is presented in Eq. (1).

$$\text{Public transit use}_{ij} = \text{city fixed effects}_j + \psi CC_{ij} + BX_{ij} + \gamma \text{Distance}_{ij} + U_{ij} \tag{1}$$

Controlling for tract average demographics (X) such as income, race, and education of the tract residents, city fixed effects and a central city dummy (CC), this regression's results yield an estimate of the propensity to use public transit as tract distance from transit changes. Distance proxies for the time cost of using rail transit. Other measures of rail transit system quality such as the frequency of trains, geographic coverage of a city's transit system and tallies of rider complaints are not as geographically precise as distance is, and will be picked up by the city fixed effects.

There are two reasons why γ in Eq. (1) could be negative. First, greater distance raises the time cost of using public transit and this increase in the full price will reduce usage. Second, we might expect to find a negative γ due to population Tiebout sorting. Those households who plan to use public transit are more likely to choose to live near transit. Since households are not randomly assigned across neighborhoods, observing that those who live close to transit use it more may not provide a reliable estimate of how the typical commuter's behavior would change if public transit became more accessible. In Eq. (1), the cross-sectional error term (reflecting unobserved average tract commuter propensity for public transit use) is likely to be correlated with distance from transit.

To account for fixed tract-level effects that might influence transit use, we estimate a difference specification based on Eq. (1). As presented in Eq. (2), we regress the census tract change in the percent of commuters using public transit on the change in distance to public transit, and the change in tract demographic characteristics.

$$\begin{aligned} \Delta\text{Public transit use}_{ijt} = {} & \text{city fixed effects}_j + \psi^* CC_{ijt} + B\Delta X_{ijt} \\ & + \gamma(\Delta\text{distance}_{ijt}) + \Delta U_{ijt} \end{aligned} \tag{2}$$

Transit improvements have differential effects on census tracts within a given metropolitan area. Some census tracts experienced significant increases in transit access while other tracts did not. This latter set of census tracts provide a useful 'control group' for inferring the counter-factual of what transit use changes would have been had access not increased between 1980 and 1990.

The city fixed effects in this difference specification control for changes in a city's transit fares, citywide changes in transit quality such as train speed, and changes in local economic conditions such as a decline in the CBD's share of jobs. For example, if a metropolitan area improves its highway system at the same time as it improves public transit, there might be little incentive for commuters to switch modes.[9] The metropolitan area fixed effects included in Eq. (2) control for such local infrastructure improvements. Our controls for the change in the census tracts' demographic composition are represented by the X vector.

We estimate Eq. (2) to measure the total effect of increased access on changes in usage. Public transit use can rise because incumbent tract residents change their behavior or because migrants to newly accessible tracts have higher public transit commuting propensities than incumbent residents. To control for this commuter sorting effect, we estimate an augmented version of Eq. (2) in which we enter the tract's share of migrants in 1990 as a regressor.

$$\Delta \text{Public transit use}_{ijt} = \text{city fixed effects}_j + \psi^* CC_{ijt} + B\Delta X_{ijt} + \eta(\Delta \text{distance}_{ijt}) + \phi(\text{migrate}_{ijt}) + \Delta U_{ijt} \tag{3}$$

We estimate Eq. (3) using GLS and IV where a tract's 1980 migration rate enters as an instrument for the 1990 migration rate. We also estimate Eq. (3) including an interaction between a tract's migration rate with its distance from transit in 1990. In those tracts which are closer to transit in 1990 and which have experienced high residential turnover, we might expect that public transit use increases as new transit users move in.[10]

5.2. Transit capitalization estimates

Our measure of public transit use is based on commuting patterns. Transit may have other benefits for local residents such as increased access to shopping and to visiting friends. Hedonic home price capitalization regressions can be used to study whether home prices have increased in areas where public transit access has improved. Eq. (4) presents the simple hedonic regression we estimate based on the change in real rents and home prices between 1980 and 1990.

[9] An examination of commuting time data using the micro PUMS reveals little evidence that private vehicle commuting times changed between 1980 and 1990 by city.

[10] We thank a reviewer for this suggestion. Migration rates are higher in tracts which have experienced increased access to transit. The partial correlation between the log change in distance and the share of a tract living there 5 years or less is −0.10 and significant.

$$\Delta\text{home price}_{ijt} = \text{city fixed effects}_j + \psi^* CC_{ijt} + B\Delta X_{ijt} + \phi(\Delta\text{distance}_{ijt}) + \Delta U_{ijt} \quad (4)$$

Estimating the regression in Eq. (4) provides new capitalization estimates and offers a cross check to study whether 'distance matters'. Positive capitalization would be evidence that transit upgrades are amenities. It is possible that transit could be negatively capitalized into real estate prices because it increases negative externalities such as noise and crime.

5.3. Which demographic groups gain from new transit?

Transit improvements may not equally improve the quality of life of all demographic groups. Transit infrastructure, and to a lesser extent operation, usually amount to a large transfer from the state and federal governments. Local government only paid for an average of 23.8% of transit expansions in the 1990s. Demographic groups may differ in their propensity to begin to use public transit. For example, younger workers who have not established commuting habits may be more environmentally conscious and more willing to use transit. As jobs have moved to the suburbs, mass transit has increasingly served reverse-commuters, mostly poor people who live in the center city and work in low-skilled jobs in the suburbs (Ihlandfeldt and Sioquist, 1989).

The 1980 and 1990 Census micro data samples allow us to study differential trends in usage by demographic group. We present evidence on which demographic groups have significantly increased their public transit use in each city. For each of the five metropolitan areas in 1980 and 1990, we present logit models of whether a working head of household uses public transit. We use the logit specifications to predict transit use in 1980 and 1990. We predict public transit use in 1990 using the 1980 demographic means. Eq. (5) presents the logit equation we use to predict a head of household's probability of using public transit in 1990.

$$\text{prob(use city } j\text{'s public transit)} = \exp(B_{j,90}X_{80})/(1 + \exp(B_{j,90}X_{80})) \quad (5)$$

This approach allows us to study how transit usage probabilities have changed by demographic group.

In addition to studying which demographic groups have substituted toward commuting using public transit between 1980 and 1990, we also examine which demographic groups are over represented in census tracts which are now closer to transit. Minorities are concentrated in central cities, and the wealthy are in the suburbs (Mieskowski and Mills, 1993; Cutler et al., 1999). Are the rich disproportionately served by new rapid transit service?

To study who gains from transit improvements, we regress the percent change in transit access on census tract demographic attributes in 1980.

$$\Delta\text{Distance}_{ijt} = \text{city fixed effects}_j + \psi^* CC_{ijt} + BX_{ij,1980} + V_{ijt} \quad (6)$$

Estimates from Eq. (6) provides evidence on which demographic groups are over-represented in increased access areas. We test the hypothesis that the reductions in distance are not randomly distributed to serve all demographic groups equally.

6. Results

6.1. Better access to transit encourages more use

Each column of Table 3 reports a separate census tract regression. The left two columns report 1980 and 1990 cross-sectional regressions where the dependent variable is the level of public transit use (based on Eq. (1)). Controlling for a host of demographics, city fixed effects, and a central city dummy, we find evidence of a negative statistically significant effect that increased distance decreases public transit usage. In 1980, an increase in transit access from the mean of 5.79 km away to 4.79 km away increases tract commuting by public transit by 1.4 percentage points. The effect is roughly the same size in 1990.

Column 3 of Table 3 presents results from the first differenced regression presented in Eq. (2). In estimating Eq. (2), we are testing whether γ is statistically significant and negative. If so, this would indicate that as a tract's distance to transit increases, public transit use falls. Column 3 shows that in a first difference specification, γ is negative and statistically significant but its coefficient is not as negative as either the 1980 or 1990 levels specifications. Columns 4 and 5 present variations on the regression listed in Eq. (3). We find that the coefficients on tract distance are robust to controlling for tract migration levels (see Column 4). The right column of Table 3 includes an interaction term between a tract's 1990 distance to transit and the tract's migration rate. This interaction term has a negative and statistically significant coefficient. This finding is consistent with a Tiebout migration effect that migrants who move to tracts nearer to transit are more likely to be public transit users. Controlling for this variable has a small effect on the distance quadratic but both terms are still statistically significant. Median regression estimates of Eq. (2) yield similar significant coefficients to the standard GLS regressions reported in Table 3.[11]

The key finding from Table 3 is that based on specification (3), the net result of moving a tract from 3 to 1 km away from transit increases average tract transit usage by 1.42 percentage points. Based on specification (5) in Table 3, of this 1.42

[11] To explore evidence of differential effects across the five cities, we have interacted the log distance to transit with city dummies. Washington, being the one city where transit use actually increased over the decade, is the only city for which the interaction coefficient is significant. Washington is fairly unique in that it is the only one of the five cities to be in the process of building its comprehensive transit system in 1980 (though there was a 3-year break between 1978 and 1981).

Table 3
How rail transit upgrades affect use[a,b]

Specification	1980	1990	1980 to 1990 change		
	(1) GLS	(2) GLS	(3) GLS	(4) GLS IV	(5) GLS IV
Constant	0.0961 (0.0342)	0.1663 (0.0601)	−0.0114 (0.0055)	0.0183 (0.0132)	−0.0012 (0.0062)
Distance to rail transit	−0.0204 (0.0013)	−0.0200 (0.0017)			
Distance to rail transit squared	0.0006 (0.0001)	0.0009 (0.0001)			
Change in distance to rail transit			−0.0083 (0.0013)	−0.0088 (0.0013)	−0.0070 (0.0014)
Change in distance to rail transit squared			0.0003 (0.0000)	0.0003 (0.0000)	0.0002 (0.0000)
1990 share of migrants				−0.0480 (0.0212)	
Interaction of log 1990 Distance and 1990 migrants					−0.0122 (0.0035)
Center city dummy	0.0995 (0.0067)	0.0660 (0.0065)	−0.0128 (0.0046)	−0.0146 (0.0046)	−0.0202 (0.0047)
Atlanta dummy	−0.0540 (0.0110)	−0.1300 (0.0119)	−0.0359 (0.0118)	−0.0386 (0.0117)	−0.0332 (0.0120)
Boston dummy	−0.0070 (0.0075)	0.0171 (0.0091)	0.0095 (0.0061)	0.0105 (0.0060)	0.0067 (0.0059)
Portland dummy	−0.0813 (0.0087)	−0.1231 (0.0087)	−0.0087 (0.0081)	−0.0124 (0.0080)	−0.0023 (0.0084)
Washington dummy	−0.0188 (0.0088)	0.0064 (0.0098)	0.0244 (0.0053)	0.0225 (0.0051)	0.0228 (0.0052)
Observations	3361	3429	3356	3354	3354
Adjusted R^2	0.7308	0.7112	0.1013	0.0981	0.1055

[a] Based on Eqs. (1–3). Dependent variable is the share of tract commuters who use public transit. Unit of analysis is the census tract. Standard errors are listed under the coefficients.

[b] Additional controls not listed: population density, quadratic of census tract household income, average tract education levels, tract share female, share college graduate, share ages 23–34, 35–44, share professional occupation, share black. These additional controls enter as levels in specifications 1 and 2, and changes in specifications 3–6. Lagged migrant share enters as an instrument for the 1990 migrant share. All of these coefficients are available on request.

percentage points, about 1.24 percentage points are due to mode switching by tract incumbents.

Fig. 1 presents three schedules of the change in transit distance needed to achieve a change in use. These schedules differ by the initial (1980) transit

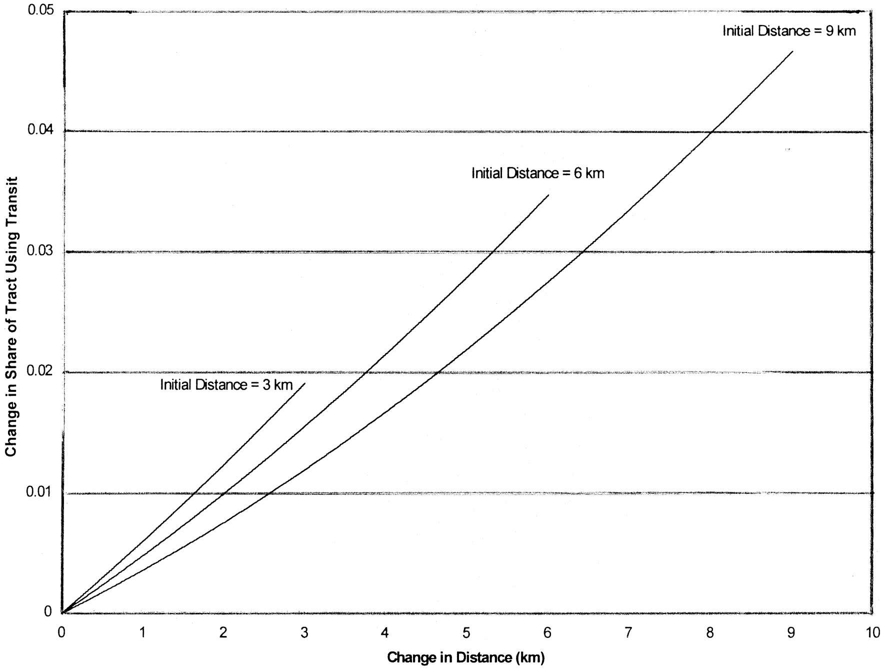

Fig. 1. Treatment effect of the change in distance to rail transit on the change in all transit use.

distance. The graph in Fig. 1 is calculated using the coefficients from specification (5) reported in Table 3. The quadratic specification of distance implies that those tracts with smaller initial distance will have a stronger relationship between the change in distance and the change in transit use.

To measure the metropolitan area impact of new transit access on use, we present regression based predictions in Table 4. We predict the number of new transit riders in each city, in response only to rail transit access improvements. At the tract level, we predict the number of new transit riders based on the coefficient on distance and distance squared, and compare this to a prediction which includes the estimated city fixed effects. We then aggregate up the tract-level predictions to the city level. The same procedure is used to calculate the predicted number of new walk and riders, except that only walk and ride tracts are included in the sample. We base our estimates on the 1980 population reported in the first column of Table 4. We use 1980 population with the idea that if rail transit induces people to move either in or out of areas being served by it, this should be taken into account both in our regression-based projections and in their comparison to actual changes in ridership. For example, based on the distance coefficients alone, we predict 45 167 new incumbent riders in Atlanta, but after including the citywide fixed effect we predict a loss of 41 560 riders, close to the even larger actual loss

Table 4
Predicted new transit use[a]

	All tracts within 25 km of the CBD				New walk and ride tracts only			
	Sample area population (1980)	Predicted new transit users based on solely distance change	Predicted new transit users based on distance and dummies	Actual change in transit use over the decade	Potential new walk and riders	Predicted new transit users based on solely distance change	Predicted new transit users based on distance and dummies	Actual change in transit use over the decade
Atlanta	1 956 444	45 167	−41 560	−67 313	878 185	27 083	−14 782	−37 039
Boston	2 356 785	1935	1848	−53 293	76 758	911	1334	−2035
Chicago	5 574 064	5655	−83 200	−33 025	82 065	1777	506	−3694
Portland	1 542 656	18 238	−6933	−52 554	336 572	10 273	3897	−10 601
Washington	4 690 733	29 225	99 322	−16 045	642 809	14 500	21 999	12 772

[a] Notes: Potential new walk and riders is calculated as the count of people who lived over 2 km from rail transit in 1980 and fewer than 2 km away from rail transit in 1990. The total predicted number of new walk and riders is based on specification (5) reported in Table 3 applied only to new walk and ride tracts. The sample used here includes all tracts with distance and population data, not just those used in specification (5).

of 67 313 riders for our sample area. Demographic shifts probably make up most of the difference between our predicted and the actual fall in ridership.[12] The results are similar for new walk and ride tracts.

Including the fixed effects in the prediction lowers the total ridership prediction in all of the cities but Washington, where predictions show a strong increase in ridership. This is consistent with past evidence that Washington's real estate values have been highly capitalized into transit, and that virtually all of new urban rail in Washington during the 1980s went to the suburbs, offsetting to some extent employment suburbanization.

Our estimate that moving a tract from 3 to 1 km away from transit increases average tract transit usage by 1.42 percentage points contributes to research which has studied how sensitive public transit demand is to changes in fares, commuting times, spatial coverage and various other relevant measures. Kain and Liu (1995) report a fare elasticity of −0.34 based on 1980 to 1990 changes in transit ridership for 75 large transit operators. This estimate matches the price elasticity measured to be about −0.33 as reported by Beesley and Kemp (1987). Lago et al. (1981) present a summary of various studies estimating elasticities of demand. They report an elasticity of −0.47 for headways (time between vehicle arrivals at a stop), 0.72 for vehicle miles of center city transit routes, and −0.55 for travel time by transit based on studies of various American cities. Voith (1991, 1993) creates a station level panel data set to study Philadelphia rail use. He finds fare price elasticities roughly comparable to earlier work and that rail riders are responsive to reduced commuting times. For example, an increase in train speed from 24 to 30 miles per hour increases ridership by 5.3% in the long run. For a comprehensive recent review of the literature on the costs and benefits of public transport projects, see Mackett and Edwards (1998).

6.2. Transit capitalization

Evidence from hedonic capitalization regressions confirm that transit is an amenity. Based on the change regressions (see Eq. (4)) reported in Table 5, a decrease in transit distance from 3 to 1 km away would increase rents by \$19 per month and housing values by \$4972.[13] Our calculations suggest that a 'walk and

[12]New walk and ride tracts are defined to be those greater than 2 km away in 1980 and fewer than 2 km away in 1990. Potential new walk and riders is defined to be the sum of the 1980 population in all such tracts.

[13]Past analysis of transit capitalization of housing prices have produced mixed results. Voith (1993) reports large rail access capitalization into Philadelphia's home prices. This capitalization grows as city employment rates grow. Voith (1999) finds the largest capitalization effects in developed urban areas where a housing supply is less elastic. Gatzlaff and Smith (1993) find weak evidence that Miami home prices appreciated as a result of its Metrorail line. However, Cervero (1994) finds that transit is capitalized in office rents in Atlanta and Washington. Damm et al. (1980) confirm that Washington property values went up in areas where Metrorail service was anticipated.

Table 5
Housing capitalization of transit[a]

	Change in census tract median rental price, 1980 to 1990		Change in census tract median home price, 1980 to 1990	
	City dummies and central city dummy but no demographic controls	City dummies and central city dummy with demographic controls	City dummies and central city dummy but no demographic controls	City dummies and central city dummy with demographic controls
Change in distance to transit	−15.75 (3.99)	−10.31 (3.03)	−5741 (2928)	−2582 (2383)
Change in distance to transit squared	0.32 (0.16)	0.21 (0.12)	109 (114)	24 (92)
Observations	3546	3499	3410	3369
Adj. R^2	0.477	0.616	0.261	0.579

[a] Note: Standard errors are in parentheses. We suppress all regression coefficients on central city dummy, city dummies, median number of bedrooms, mean number of rooms. The dependent variable in the change regressions is the percent change in rents or housing values. The regressions are based on Eq. (4) in the text.

rider' living in tract which becomes closer to transit could save over $1200 a year. Given that real estate prices in improved access tracts have not increased nearly as much, this suggests that renters who are 'walk and riders' are major beneficiaries of new transit. They save commuting time and their rents have not increased proportionately.

6.3. Transit use and transit access by demographic group

Micro data allow us to study which demographics groups have increased their use of public transit. Tables 6 and 7 present logit estimates of whether a head of household uses public transit to commute to work for each of the five cities. The specifications control for age, occupation, race, income, sex, marital status, education, and a central city dummy. The coefficient estimates in Tables 6 and 7 are used to predict public transit use in each city, in 1980 and 1990 for different demographic groups.

Predicted probabilities of public transit use, by demographic group, are presented in Table 8. In all the cities together, the poor reduced transit use from 24.6 to 18% between 1980 and 1990. With the exception of Portland, the poor are quitting transit faster than average. In Boston even though overall predicted use has fallen, college graduates and the young increased their likelihood of using public transit. Based on Eq. (5), we predict that the average head of household age 22–34 in Boston increased his probability of using public transit from 13.8% in 1980 to 15.9% by 1990. The average college graduate commuter's probability of

Table 6
1980 Public transit use logit estimates using census microdata[a]

	Atlanta	Boston	Chicago	Portland	Washington DC
Professional dummy	0.011	0.113	0.305	0.369	−0.010
	(0.150)	(0.091)	(0.054)	(0.170)	(0.075)
Dummy for ages 20–34	0.055	−0.215	−0.159	0.112	−0.048
	(0.156)	(0.095)	(0.054)	(0.180)	(0.083)
Dummy for ages 35–49	0.041	−0.255	−0.246	−0.103	−0.229
	(0.166)	(0.097)	(0.055)	(0.204)	(0.086)
Black	0.839	0.626	0.181	0.266	0.403
	(0.136)	(0.137)	(0.059)	(0.370)	(0.079)
Other	0.551	0.246	0.043	0.447	0.619
	(0.550)	(0.224)	(0.092)	(0.349)	(0.162)
Household income	−3.268	−1.530	−1.857	−1.305	−1.172
	(0.717)	(0.464)	(0.260)	(0.946)	(0.383)
Household income squared	2.341	1.006	1.414	0.109	0.535
	(0.576)	(0.362)	(0.195)	(0.878)	(0.293)
Female	0.700	0.547	0.439	0.925	0.343
	(0.147)	(0.098)	(0.059)	(0.178)	(0.079)
Married	−0.403	−0.288	−0.388	−0.338	−0.491
	(0.163)	(0.100)	(0.058)	(0.187)	(0.082)
Central city dummy	1.272	0.949	1.091	0.917	1.122
	(0.131)	(0.086)	(0.047)	(0.145)	(0.075)
College graduate	0.250	0.405	0.629	0.325	0.543
	(0.152)	(0.093)	(0.055)	(0.168)	(0.077)
Constant	−2.800	−1.779	−1.758	−2.742	−1.779
	(0.241)	(0.153)	(0.093)	(0.301)	(0.139)
Observations	5401	6638	17 338	2821	8681
Pseudo R^2	0.177	0.082	0.100	0.114	0.108

[a] Notes: The dependent variable equals one if the worker commutes using public transit and zero otherwise. Standard errors are listed below coefficients. Summary statistics are available on request. Regressions are based on 1980 Census of Population and Housing 1% Sample micro data. The omitted category is a white male non-professional who is over age 49, not-married and lives in the suburbs and does not have a college degree.

using public transit in Boston increased from 13.7 to 14.7% between 1980 and 1990.

Given that each census tract is not a microcosm of the city's population, improvements in transit will have differential impacts on the population. Table 9 uses the census tract panel data set to identify the major beneficiaries of transit improvements. We present regressions of the propensity for new rail transit to

Table 7
1990 Public transit use logit estimates using census microdata[a]

	Atlanta	Boston	Chicago	Portland	Washington DC
Professional dummy	−0.050	0.086	−0.015	0.202	0.085
	(0.176)	(0.094)	(0.068)	(0.209)	(0.076)
Dummy for ages 20–34	−0.081	0.175	0.245	−0.172	−0.090
	(0.176)	(0.103)	(0.073)	(0.233)	(0.088)
Dummy for ages 35–49	−0.019	−0.157	0.031	−0.071	−0.007
	(0.171)	(0.102)	(0.070)	(0.220)	(0.080)
Black	1.619	0.591	0.442	0.624	0.665
	(0.150)	(0.151)	(0.076)	(0.386)	(0.078)
Other	0.857	0.367	0.018	0.805	0.565
	(0.349)	(0.159)	(0.089)	(0.278)	(0.111)
Household income	−1.776	−0.340	0.003	−1.476	−0.777
	(0.503)	(0.269)	(0.172)	(0.594)	(0.206)
Household income squared	0.408	0.004	0.056	0.389	0.172
	(0.248)	(0.117)	(0.064)	(0.198)	(0.083)
Female	0.442	0.254	0.553	0.468	0.505
	(0.154)	(0.095)	(0.070)	(0.203)	(0.076)
Married	−0.404	−0.487	−0.367	−0.639	−0.353
	(0.169)	(0.099)	(0.071)	(0.221)	(0.080)
Central city dummy	1.250	0.941	1.110	1.131	1.177
	(0.141)	(0.091)	(0.060)	(0.187)	(0.068)
College graduate	0.284	0.482	0.748	0.135	0.563
	(0.168)	(0.097)	(0.069)	(0.210)	(0.080)
Constant	−3.509	−2.123	−2.723	−2.846	−2.403
	(0.255)	(0.143)	(0.106)	(0.313)	(0.129)
Observations	6645	6295	11 612	2582	9534
Pseudo R^2	0.211	0.077	0.103	0.115	0.117

[a] Notes: The dependent variable equals one if the worker commutes using public transit and zero otherwise. Standard errors are listed below coefficients. Summary statistics are available on request. Regressions are based on 1990 Census of Population and Housing 1% Sample micro data. The omitted category is a white male non-professional who is over age 49, not-married and lives in the suburbs and does not have a college degree.

serve the young, blacks, homeowners, and the wealthy, along with a multivariate regression including all of these demographic groups. Results of Table 9 indicate that blacks and the young were not served by transit expansions, probably because of the tendency for expansions to be in suburban, or outer-center city areas. The college educated and home owners were over-represented in census tracts which were closer to public in 1990 relative to 1980.

Table 8
Predicted transit use for each demographic group[a]

Demographic group	Atlanta		Boston		Chicago		Portland		Washington	
	1980	1990	1980	1990	1980	1990	1980	1990	1980	1990
All	0.035	0.024	0.115	0.113	0.131	0.116	0.064	0.037	0.126	0.104
Ages 20–34	0.044	0.029	0.138	0.159	0.145	0.142	0.081	0.042	0.152	0.115
College graduate	0.034	0.022	0.137	0.147	0.184	0.170	0.081	0.040	0.141	0.119
Non-college graduate	0.036	0.025	0.104	0.096	0.116	0.100	0.058	0.036	0.117	0.095
Income$\leq$20	0.111	0.065	0.209	0.174	0.246	0.180	0.131	0.081	0.241	0.191
20$<$income$\leq$50	0.038	0.026	0.121	0.117	0.143	0.121	0.066	0.038	0.147	0.119
50$<$income	0.020	0.011	0.090	0.086	0.108	0.094	0.036	0.022	0.092	0.076

[a] The 1980 predicted probabilities are based on 1980 logit estimates for each city. To calculate the probability that a working head of household uses public transit we predict transit usage using the mean attributes from 1980. The 1990 predicted probabilities are based on Eq. (5) in the text. Household income is measured in $1000s of 1990 dollars.

Table 9
How improved transit access affects different demographic groups[a]

Specification	(1)	(2)	(3)	(4)	(5)	(6)
% homes occupied by owners	−0.1796 (0.0654)					0.0049 (0.1255
Median income		−0.0028 (0.0045)				0.0065 (0.0064
Median income squared		−0.0000 (0.0000)				−0.0000 (0.0000
% with more than 16 years of education			−0.3068 (0.1398)			−0.3086 (0.2015)
% of population ages 22–34				0.4579 (0.1982)		0.9989 (0.3400
% black					0.2950 (0.0558)	0.3367 (0.0721
Center city						0.0334 (0.0703)
Observations	3354	3354	3354	3354	3354	3354
Adjusted R^2	0.3628	0.3633	0.3630	0.3616	0.3765	0.3820

[a] Note: The dependent variable in each regression is the percent change in distance to transit for the census tract between 1980 and 1990. See Eq. (6) in the text. Standard errors are in parentheses. The specification also includes city dummies. Unit of analysis is the census tract.

7. Conclusion

Exogenous growth in rail transit access brought about by transit improvements in five cities during the 1980s allows the opportunity to study the impact of urban rail transit upgrades on use, on the behavior of different demographic groups and on real estate values. Using geographical mapping software we created a unique data set of each census tract's change in access to transit, proxied for by distance. Merging this data to 1980 and 1990 census data, we exploited within metropolitan area changes in distance to transit to provide new insights into the effects of urban rail transit upgrades. We find a small behavioral response of incumbent residents toward increased commuting by public transit, and a small capitalization of transit infrastructure into housing prices and rents. We have demonstrated that rail improves property values and gets a few people out of their cars, reducing congestion and improving the environment.

The continued building of rail transit in St. Louis, Los Angeles, and San Diego provides additional testing grounds to study its impact. One possible extension of this research would be to use hedonic methods to study whether cities that build rail experience an improvement in their cross-city quality of life ranking.

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Appendix. Data sources

1980 Census of population and housing, summary tape file 3a:

The files for The District of Columbia, Georgia, Illinois, Maryland, Massachusetts, Oregon and Virginia were downloaded from the Harvard–MIT Data Center.

Census tract records for the Atlanta, Boston, Chicago, Portland and Washington MSAs were extracted from these files for building the variables of interest.

1990 Census of population and housing, summary tape file 3a:

This data was taken from a series of CD-ROMs from which Wessex software was used to extract tract-level data. Data for all of the counties that make up at least part of each of the relevant MSAs was extracted, from which the relevant variables were built.

MABLE geographic database

Relevant data extracted using the Mable/Geocorr version 2.5 Geographic Correspondence Engine (http://plue.sedac.ciesin.org/plue/geocorr.html)

National Transportation Atlas Databases 1996 CD-ROM, Transit File

TIGER Database of local boundaries

Transit histories:

Chicago Transit Authority pamphlet in commemoration of CTA's 40th anniversary, 1987 (http://members.aol.com/chictafan/ctardate.html).

Atlanta's MARTA History (http://www.itsmarta.com/history.html).

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