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Income Elasticity of Demand for Large, Modern Rapid Transit Rail Networks

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Abstract

In spite of evidence to the contrary, there is a common perception inside of academia and out that rail transit is an inferior good. This paper proposes a demand model for radial subway networks utilizing the monocentric city model in order to quantify the income elasticity of demand. This model is tested against extant data from the 2000 Census, and controls for spatial variability, demographic and economic factors, and commuter costs. This paper concludes that while the factors that drive demand vary across urban areas, the results suggest that rail transit may in fact be a normal good.

Keywords

Elasticity, Urban Economics, Public Transportation

Cover Page Footnote

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1. Introduction

A common perception of public transportation, whether rail, autobus, or other forms, is that it functions as a means of transportation for middle- to lower-income urban residents, and in effect is an inferior good.[2] To that end, networks have often been built with the objective of either expanding access to downtown for high densities of potential commuters and also as a method for lower income city residents to be more mobile. This has been particularly true of the past 40 years, when public transportation has become an essential part of the designs of urban planners.

Determining definitively whether rail transit is an inferior good or a normal good could have important real-world implications. Choosing which groups of consumers to target with expansions or upgrades to rail transit is a critical policy-making question with many millions of dollars at stake. Further, from a public policy point of view, if it is known that rail-transit is not an inferior good would perhaps lead policy makers to choose other forms of public subsidies to increase mobility among the poor.

This paper seeks to examine and test this perception as a hypothesis on a subset of American rapid-transit rail transportation networks. Drawing on the theoretical and applied work of other economists, this paper constructs a model whose principal units are census block groups – the smallest geographical unit available for which Census sample data is collected. Especially emphasized are the heterogeneous nature of the choices faced by commuters and the character of the cities and networks themselves.

This paper limits its field of study to a relatively narrow number of transit systems for theoretical and practical reasons. Cities with relatively robust networks were selected so that a large number of block groups across a wider spatial array would be included. Cross sectional data from the 2000 Census is used to test the hypothesis.

Initially, census block groups whose centroids are within a two kilometer radius of a subway station are retained. Indicator variables are used to identify each city's network. A basic model is proposed, and a log-log OLS regression is performed to quantify the model and control for exogenous variability. The results indicate that across all geographies rail transit is a normal good and the cost of rail transit is found to be relatively price elastic.

2. Literature Review

While the popular view is that public transit is an inferior good, those studies that have included income in their studies of the behavior of consumers of public transit have produced results that are either ambivalent or do not confirm to this view. Nonetheless, no study has yet tried to address this specific problem as the main focus.

Various authors have found widely diverging results for the income elasticity of demand for busing routes, as detailed by Holmgren (2007). He found using a meta-analysis that estimates on the income elasticity of demand for public buses were ambiguous and highly dependent on the demand specifications included. He found that while some studies had found negative income elasticities of demand, some had also found positive results, and that the overall average was 0.17.

Several authors have investigated the demand for public transportation on a route by route basis.[3] Schmenner (1975) pursued a methodology of restricting his area of study to populations within two city blocks of bus routes in three Connecticut cities. The study found that in bus transit with the log of revenue per mile or revenue per hour as the dependent variable, the sign on the log of family income was positive when all three cities in his study were pooled. When performed on a city by city basis, the sign on family income fluctuated, seeming to indicate that city-specific factors were key drivers behind this result. Further, he claimed that previous studies had suggested that demand for busing was price inelastic.

Schmenner's finding is important because it suggests that if a relatively slow form of public transit would in fact have a positive income elasticity of demand, than faster forms would also. Glaeser, Kahn, and Rappaport (2006) found that the fixed time-cost of subways is less than that for bus transit, and that subways had on the whole a "much lower" time-cost per mile. The paper also found that when surveying all modes of public transit with 2000 census tract data in Boston, Chicago, New York, and Philadelphia that there was a positive correlation between the log of income and public transit usage for fixed distances outside of the Central Business District. When changing the urban mix to Houston, Atlanta, Pheonix, and Los Angeles, the authors found that the correlation was negative. Differing levels of urban residential and employment concentrations seem to produce different patterns of transit usage according to this study. While the first set of cities was specifically selected to include subway transit, the study did not attempt to find separate results on income for rail and bus transit.

A factor that could influence this outcome is discussed by Glaeser, Kahn, and Rappoport (2006) is the age of the cities and their transit networks as an important factor in the relationship between income and public transit usage. Baum-Snow, Kahn, and Voith (2005) found that in networks that have been built or extended between 1970 and 2004, poorer census tracts were 20.6% more likely to have gained access to rail. Later day rail transit operations and expansions are funded and directed by local, state, and federal governments.[4] The greater likelihood for poorer tracts to receive new rail transit could be explained as a purposeful decision by policy makers. This is in contrast to the first period of rail transit construction, which was largely initiated by private companies. Later-day urban rail transit expansions are sometimes constructed as a policy tool to address, in part, problems of urban poverty. For example, Gilderbloom and Rosentraub (1990) specifically recommend that policy makers utilize mass transit as a method for improving opportunities and promoting independence of the poor, elderly, and the disabled in the Houston area.

Another cause that could drive this finding is that the "newer" cities are much less centralized and dense than older ones. In a paper by Anas, Arnott, and Small (1998), they explain that in cities who saw most of their growth prior to the invention of the automobile, the rich outbid the poor for the most centrally located living spaces. With the construction of electric streetcars, the rich moved outwards from the city center and settled along mass transit line to create the first "streetcar suburbs".[5] Cities whose growth was driven by the construction of radial freeways or at the beginning of the streetcar period are far more dispersed than those settled before. For example, Poulton (1980) points out that Los Angeles developed the world's largest streetcar system which allowed for greater dispersal, a facet also remarked upon by others, such as Gordon and Richardson (1996).[6] There exists some evidence that cities that construct subway lines can spur increased residential densities along the mass transit corridors, even in cities where automobile use is widespread, such as in Davies (1976).[7]

Yet even in "newer" cities, there is some evidence that the role of income as a predictor of public transit usage cannot be assumed to automatically reverse. Dajani, Egan, and McElroy (1975), conducted a study using the Metropolitan Atlanta Regional Transit Authority's transit planning studies showing that when dividing up the metro Atlanta area into zones, the coefficient on family income was positive, but not statistically significant. The key driver of rail transit usage seemed to be distance to the nearest transit station which was statistically significant at the 0.01 level. The chief drawback of this study was that it measured net benefits from the presence of a heavy rail system as opposed to ridership directly, and had few degrees of freedom. Nonetheless, it is somewhat counterintuitive that Atlanta, which has relatively lower costs of daily parking[8] (an indicator of employment concentration in the CBD[9]), would show a positive relationship between net benefits and income.

On a city-wide basis, further evidence is inconclusive about the sign on the income elasticity of demand for transit. Schenker and Wilson (1967) showed that when compared across twenty-three metropolitan areas, the sign on family income was positive, but not statistically significant. However, also using 1960 Census data, Meyer, Kain, and Wohl (1965) found that the sign on income on public transportation usage was negative when doing a cross-sectional comparison that did not involve econometric analysis.

The theoretical basis of all of these studies is centered on the premise that a city is monocentric in nature. This assumes that all residents of a city commute to the central business district for their employment. There are obvious problems with this assumption. Glaeser and Kahn (2004) and Anas, Arnott, and Small (1998) have found that only 75.9% of metropolitan area employment in the year 2000 was within three miles of the CBD. Available evidence indicates, however, that mass transit commuters tend to overwhelmingly work in the CBD. Rothenberg Pack (1992) states that 70% of SEPTA commuters work in downtown Philadelphia. Baum-Snow, Kahn, and Voith (2004) also indicated that the vast majority of public transit users were commuting to the CBD across the sixteen cities under study using data from the 1990 Census.

A casual study of the layout of these systems reveals why. Most are designed as a spoke and wheel system, where the lines radiate outwards from the Central Business District. With the exception of New York's G Train and Philadelphia's Norristown High Speed Line, all heavy rail lines in the United States run towards or very near the Central Business District. While this is somewhat less true of light rail lines, the easy majority also follow the same pattern.

For this reason, like other authors incorporating the monocentric city model into studies of public transit, the model is a reasonable approximation of how rail transit commuters behave.

3. Model

- Theoretical Model

In the standard monocentric city model, a continuum of individuals distribute themselves over the available geography such that in equilibrium, everyone has maximized their utility.[10] All consumers commute to work in the Central Business District (CBD). Consumers are endowed with one unit of time to use for commuting, t, and a utility bundle composed of a basket of consumer goods, c, and living space, s. Utility is maximized by minimizing the amount spent on t, and obtaining the most preferred combination of c and s. Rail lines emanate in a radial fashion from the CBD.

The monocentric city model indicates that consumers will choose to distribute themselves spatially, in part, on how they most effectively minimize their commuting costs while also maximizing their housing space and other consumer goods. To this end, those consumers who live within easy access to rail transit have multiple ways they can minimize *t*.

In this formulation, where block groups have been restricted to those within easy walking distance of a subway station (defined here to be 2 kilometers, or a walking time of roughly 33.33 minutes), there are three commuting options: (1) walking to the nearest subway station and taking the rapid transit line to the CBD, or (2) driving directly to the CBD, (3) walking to the CBD.

In commuting option (1), commuters choose to walk to the nearest subway station. There is a fixed waiting period for a train, which is equal to half the time between rush hour headways.[11] Upon paying the transit fare, the consumer then commutes to the CBD in time β. Thus, the cost of commuting by public transportation is equal to:

$$w[\alpha + \beta + \text{Waiting Time}] + f$$

Where w is the average hourly wage, α is the time it takes to walk in hours to the nearest subway station, β is the time it takes to commute to the CBD from the subway station, and *f* is the price of one transit fare.

In commuting option (2), commuters choose to drive directly from their residence to the CBD. Vehicle ownership incurs a high pecuniary cost, but the marginal cost of one additional commute downtown is much lower. The marginal cost is calculated by adding the time-cost incurred to drive to the CBD in hours, $w\gamma$, plus the price of the gas consumed to commute which is equal to the inverse of the average kilometers per gallon consumed during city driving by a vehicle times the distance from the place of residence to the CBD times the cost of a gallon of gasoline. Lastly, the price of daily parking is then included:

$$w\gamma + g\rho(\delta)^{-1} + P$$

Where w is the average hourly wage, g is the price of a gallon of unleaded gasoline, δ is the average kilometers traveled per gallon consumed during city driving by a car, ρ is the distance from the place of residence to the CBD, and P is the cost of daily parking in the CBD.

It is assumed that for someone living within close proximity to rail transit, then taking a bus to the CBD is never going to be preferred over taking rail. The key difference between a rail line versus a bus route from the same starting point heading towards downtown is that bus transit will take longer. Buses would have to go through the traffic that a train on a dedicated (or even semi-dedicated) right of way will not have to face, in addition to generally having more stops and lower capacity.

However, it is conceivable that for those commuters living just adjacent to the CBD, walking to work would be the most cost-effective option.[12] The cost function for walking to work is:

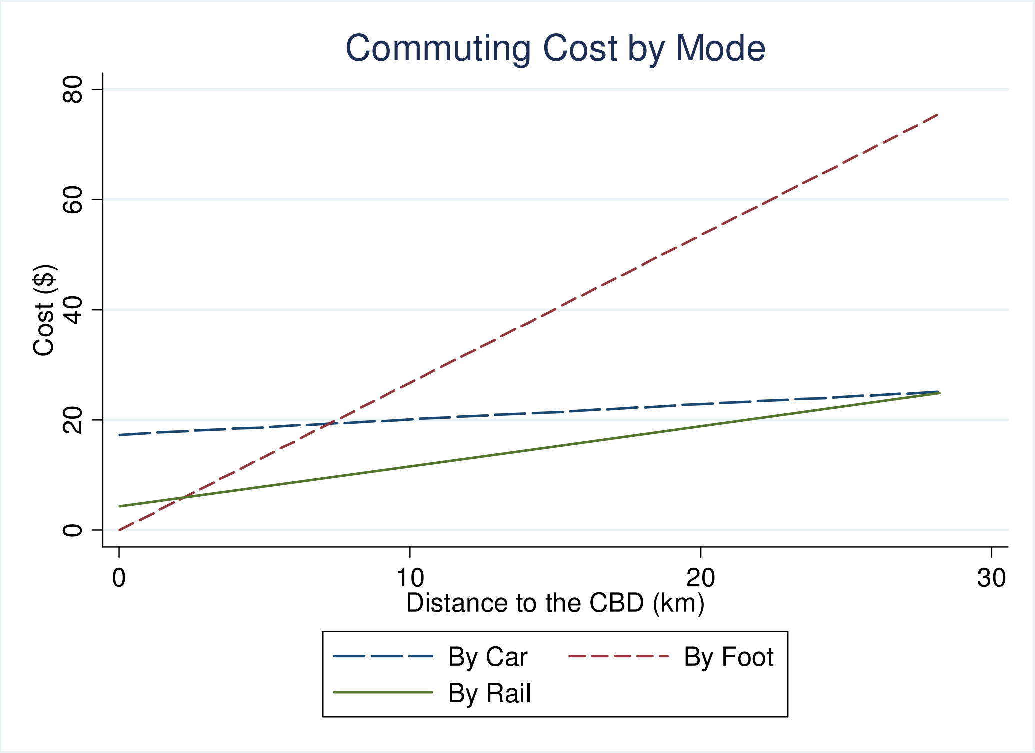
$$w\tau$$

Where *w* is the average hourly wage and *τ* is the average time in hours it takes to walk from a point A to the CBD.

Thus, *ceteris paribus*, the function that determines the method of commuting to the CBD is:

$$\min[w[\alpha + \beta + \text{Waiting Time}] + f,\ w\gamma + g\delta\rho + P,\ \ w\tau]$$

Graphing each function using observed data for each mode shows that there is a range of about 2 to 28 kilometers where rail transit is the least costly form of transit[13]:



- Empirical Model

The empirical model to test the hypothesis outlined above is:

Log(Rail Transit Commuters$_{ij}$) = $\beta_0 + \beta_1$*log(Median Household Income$_{ij}$) + β_2*log(Cost of Commute by Rail Transit$_{ij}$) + Other Controls$_{ij}$, where i indexes the block group, and j indexes the city.

Median household income is the independent variable used to determine the relationship between ridership and income. The cost of commute by rail transit is determined from the first equation specified in the "Theoretical Model" section. Cost of walking and cost of commuting by car are included under "other controls". Other controls were included to help ensure that the result would properly take into account factors that may influence rail commuting independent of income.

This model should not be read as an attempt to find out the relationship between household income and ridership assuming that the price of all modes of commute are in market equilibrium. Transit prices, *prima facie*, are *not* in equilibrium and are (often heavily) subsidized to promote usage. Frankena (1973) found that these transit subsidies are net regressive in terms of income.

There are several empirical factors that could determine the choice of transport mode in addition to a cost calculation. There exists a perception of public transit as being attractive to criminals. Although Ihlanfeldt (2003) showed that it is more likely that the presence of a subway station lowers the rate of overall crime, especially in suburban neighborhoods, it is possible that access to rail transit could increase crime near center city stations. The number of occupied housing units as a percentage of all housing units is taken as a proxy for the relative safety of a neighborhood. It would follow that exceptionally unsafe neighborhoods would have higher rates of vacant houses. Census block group that had large populations of retirees or college students might have artificially low numbers for people who commute by subway, because they do not need to go to work. Further, census blocks with unusually high populations of women might be ones where incomes are lower than the median due to gender wage disparities. Higher proportions of women could also conversely be an indicator of higher incomes, due to the presence of a larger population of single mothers who would need to work multiple jobs to support children.

Several specific features of the city and the network are controlled for. A dummy variable for the presence of a university is included as a means for controlling for the fact that the population mix and behavior around a college is likely to be different than in the population at large. Additionally, since all of the streetcar service in the cities under study is operated on light rail systems, the definition for light rail used in this study is those rail services which do not have a fully grade separated right of way. Block groups which are only close to a light rail line are indicated with a dummy variable for light rail.[14]

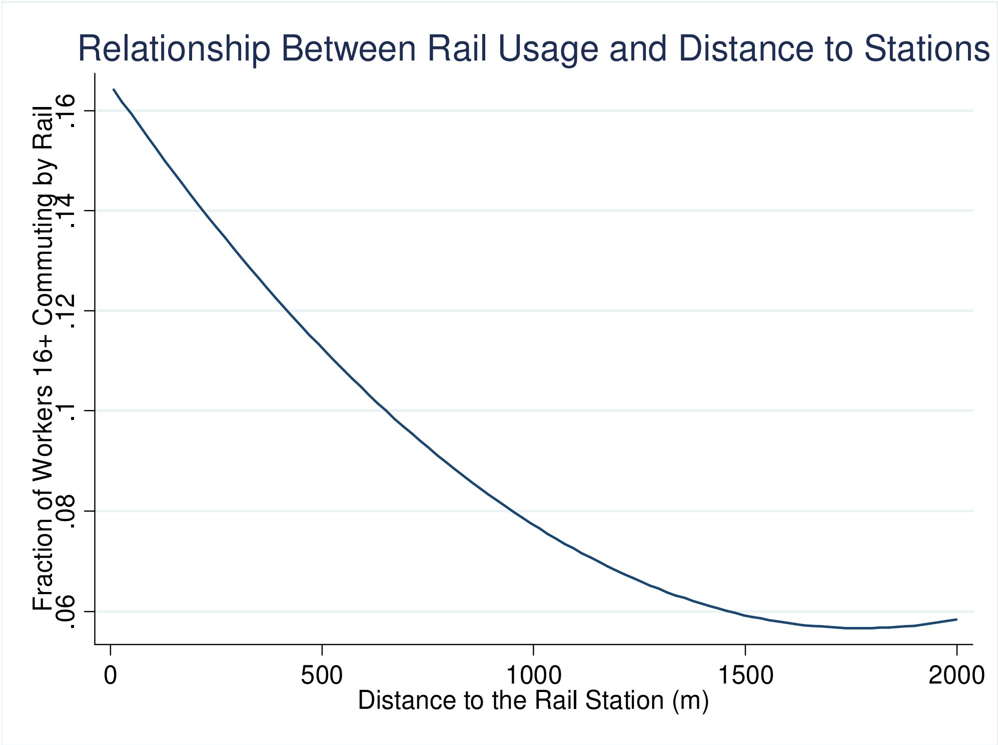
Another factor controlled for is high residential density. The density can be so high that regardless of the cost of commuting *to* downtown, owning a car is either very expensive or very difficult, due to difficulties obtaining a parking space. The number of households owning no cars is included to control for the feasibility of owning a car.

Population densities have other implications, namely that while the CBD may have the highest concentration of jobs in the urban area, there could be significant concentrations of jobs outside of it. All of the cities under study have lines that run specifically towards the CBD, and thus it is possible to be reasonably confident that a large number of rapid rail commuters are going to the CBD. However, it cannot be completely discounted that certain block groups will have a bias towards lower rates of subway ridership than we would otherwise expect due to proximity to a jobs cluster outside of the CBD. Voith (1995) suggests that this may well be the case, as an artificially low cost of auto commuting can actually lead to a *lower* concentration of jobs in the CBD.

One critical factor this study seeks to control for is the impact of the size of the network. A large network would present a more attractive model for a worker to use to commute to downtown, because it suggests a greater investment in the transit infrastructure. This greater investment could manifest itself in several ways, one of which being the perception that on-time service is likely to come with a stronger guarantee. Dummy variables on each city are intended to capture, at least in part, any network and city specific effects.

Public transit has often been lauded as a more environmentally friendly form of transportation. Anderson and Mizak (2006) identified college graduates as being most likely to hold environmentalist beliefs. The model considers those who are most likely to have pro-environmentalist views to account for commuters who would choose to take rail transit specifically as an environmentally-friendly option.

It is possible that at a certain distance from a rail station, commuters could encounter bus lines that run towards the CBD where the total cost of commuting by subway is more than the cost of the commuting by bus, even accounting for the increased time spent in transit. This possibility would likely be especially true of a streetcar. Evidence from the data shows that the percentage of residents taking rail transit comes close to zero before the 2 kilometer mark:[15]



The minimum point of the curve is at the 1,722 meters mark. Accordingly, the regression analysis is only performed on those census block groups within a 1.722 kilometer range of a rail station. Unless stated otherwise, all tables and graphs include the full 2 kilometer limit.

Historically, rail lines and subways were constructed to serve not only existing densities of commuters, but also to develop new housing lots. This pattern of development was especially true in Boston, Philadelphia, and Chicago, where large parts of the networks as of the year 2000 had been built a century or more ago. Older housing units tend to be smaller in size and space than newer ones, implying that especially in those three cities, there might be significant interaction occurring between the median number of rooms per housing unit and the distance from the subway. Even in cities with newer networks, Davies (1976) found that the presence of a rail line may encourage higher density in and of itself. An interaction term between the distance to the rail station and the median rooms per housing unit is used to control for this relationship and its impact on commuter's consumption of *s*, living space.

The nature of employment could be a key determinant of how residents choose to commute. Neighborhoods with large numbers of unemployed workers are likely to also have large numbers of underemployed or part time workers who would be less likely to travel to the type of white-collar jobs that cluster in the CBD.

Lastly, this study also seeks to control for these factors in making its determination about the proper relationship between income and the propensity to choose public transit. The log of household median income is used to find the income elasticity of demand. The monocentric city model indicates that in addition to accounting for commuting costs, residents will choose a distance from the CBD that maximizes their living space, *s*, and a basket of consumer goods, *c*. The median number of rooms in a household, the median contract rent, and the distance from the CBD are controlled for.

Based on this spatial model of transit, a log-log OLS regression is performed to estimate the income and price elasticities of demand for rapid rail transit for those census block groups that are within two kilometers of a subway station across all four cities. Four more regressions are run for each city individually, and a last regression is run on just those census block groups with access to heavy rail transit.

4. Data

Rail systems were selected from cities that had one well-defined downtown area to ensure that the structure of the network would broadly conform to the monocentric model. Additionally, cities with larger networks were chosen to ensure a wider exposure to varying demographic and economic indicators.

The criteria for inclusion were as follows:

- Eleven cities had at least one heavy rail rapid transit line in the year 2000: Atlanta, Baltimore, Boston, Chicago, Cleveland, Los Angeles, Miami, New York, Philadelphia, San Francisco, Washington
- Of those, six had at least two heavy rail lines and two light rail lines OR three heavy rail lines: Boston, Chicago, New York, Philadelphia, San Francisco, and Washington.[16, 17]
- Of those, four had one well-defined downtown area served by rail transit: Boston, Chicago, Philadelphia, and Washington.[18]

Larger networks also have the advantage of a network effect that smaller networks may not. More lines mean more connections, and more connections mean that the public transit becomes more and more of an attractive means of getting downtown. Since this kind of network effect would possibly be a significant difference between smaller networks versus larger ones, for the sake of comparing like to like, smaller networks were excluded.

The building block of this model was a list of every operational subway station as of the year 2000 in the four cities under study. A list of addresses was created from publicly available sources.[19] These addresses were then converted into latitudinal and longitudinal coordinates.[20] Census block groups from the 2000 Census were used a cross-sectional database from which to match subway stations to population centers. The distance from the centroid of a census block group to each subway station in the system in the subject counties was calculated in meters. These census block groups were then culled to keep only those within two kilometers of at least one subway station.

The measure for the dependent variable was the total number of workers aged 16 and over who commuted to work by rail transit. The census information does not include information on the number of rail transit commuters who work in the central business district.

Additional information on demographics and economics of the block groups, data was gathered from the U.S. Census. Bureau of Labor Statistics data was used for average gasoline prices for each urban area. Central Business Districts were identified from the 1982 Census of Retail Trade, which identified the census tracts that constitute the downtown area of each city. A visual inspection of these census tracts confirmed that they fit with the generally held notions of the location of each city's downtown.

Parking rates were obtained from Colliers International. To derive the daily parking rate in downtown in the year 2000, year-on-year growth in monthly unreserved parking rates were calculated between 2000 and 2001. These rates were then applied to the 2001 daily parking rates to obtain the 2000 daily parking rates.

Google Maps' travel planner was used to calculate the travel time and distance, and an average speed for each mode of transit. This data was then supplemented by Texas A&M's Texas Transportation Institute Annual Urban Mobility Report, wherein a congestion factor unique to each urban area was applied to the time to commute downtown.[21] Further, the Annual Urban Mobility Reports included a value of time spent commuting, in dollars per hour. This value is a national average, thus the model is not sensitive to variations in valuations of time across geographies.[22]

Finally, the cost of commuting downtown by public transportation was derived from using average speeds as calculated from Google Maps travel planner. Where necessary, a different average speed was calculated for light rail as opposed to heavy rail lines, but otherwise, averages speeds were assumed to be the same across all lines within those two categories. As discussed above, the working definition of light rail lines for the purposes of measurement is those lines which do not have a fully dedicated right of way.[23] These lines that are nominally or technically light rail lines were reclassified as Heavy Rail.

- Selected Descriptive Statistics

Table I below summarizes some key variables used in this analysis:

Table I								
City	**Boston**		**Chicago**		**Philadelphia**		**Washington, DC**	
	Mean	σ^2	Mean	σ^2	Mean	σ^2	Mean	σ^2
Median Household Income	$49,130	$25,209	$41,080	$19,804	$37,725	$23,021	$58,298	$30,047
Commute Cost by Rail	$7.80	$3.50	$11.30	$3.50	$10.20	$4.40	$10.90	$4.20
Commute Cost by Car	$26.00	$1.30	$22.00	$1.50	$16.20	$1.80	$14.00	$1.90
Commute Cost by Foot	$12.70	$9.20	$26.30	$11.90	$22.40	$13.90	$20.00	$13.80
Median Contract Rent	$791.93	$292.11	$570.47	$218.67	$511.33	$224.26	$811.96	$357.68
Daily Parking Price	$24.27		$18.67		$13.37		$11.31	
Price of Gallon of Unleaded Gasoline	$1.59		$1.64		$1.55		$1.58	
Fare Price	$0.89		$1.96		$1.60	$0.12	$1.81	$0.71
Average Population per Block Group	1,378.1	616.2	1,814.3	1,499.0	1,127.8	536.3	1,810.3	976.5
Population Density	21,736	18,242	23,763	15,256	20,115	14,148	13,354	12,089
Median Rooms per Housing Unit	4.68	1.3	4.77	0.96	5.57	1.19	5.04	1.74

Distance to Rail Station (meters)	828.9	537.6	780.6	501.4	711.7	536.2	1,072.40	507.7
Distance to the CBD (km)	4.73	3.45	9.81	4.44	8.37	5.2	7.47	5.14
Mean Time to Work	28.58	5.85	34.9	7.77	31.16	8.79	30.46	5.66
Fraction of Housing Units Occupied	96.0%	3.1%	92.6%	6.1%	89.9%	8.2%	93.9%	5.9%
Fraction between Ages 15-24 and 65+	29.3%	13.7%	25.6%	7.7%	28.5%	10.9%	24.8%	10.7%
Fraction Minority	37.7%	29.2%	65.6%	31.6%	53.8%	38.3%	57.1%	31.9%
Fraction Bachelor's Degree or Higher	52.1%	33.4%	36.8%	31.1%	31.9%	31.8%	58.6%	33.2%

- Boston

The MBTA's rapid rail network is extensive – approximately 10% of the population of the Boston Urban Area lives within ½ a kilometer from a subway station. The MBTA has three heavy rail rapid transit lines, and five light rail lines: the Green Line, which is composed of four branches and the Ashmont-Mattapan High Speed Line, which is technically a branch of the city's heavy-rail Red Line. The Green Line is the most heavily used light rail line in the United States. When the full 2 km radius is calculated, the number of people within close proximity to rail transit expands to over 1,100,000, and about 31% (1003/3255) of the block groups in the Boston Urban Area are within two kilometers or less of a subway station, as seen in Table I. The area adjacent to the subway network has a higher proportion than minorities than the urban area as a whole, but only slightly more so than the national average.

A comparison of the racial composition of the service area versus the urban area shows that it skews more heavily towards minorities than the urban area as a whole. However, the area within the 2 km radius of a rail station is roughly similar in terms of the proportion of black and Hispanic residents to the United States as a whole.

Table II

		Between the Two Zones		**Within Each Zone**			
		Block Group Count	**Total Population**	**White, Non-Hispanic**	**Black, Non-Hispanic**	**Asian, Non-Hispanic**	**Hispanic**
	> 2 km from a subway station	69.2%	72.7%	86.7%	2.7%	3.3%	5.1%
	≤ 2 km from a subway station	30.8%	27.3%	62.3%	14.0%	8.6%	10.7%
Boston	Total Population			80.1%	5.8%	4.7%	6.7%
	> 2 km from a subway station	61.2%	66.3%	68.4%	13.4%	4.2%	12.4%
	≤ 2 km from a subway station	38.8%	33.7%	34.3%	31.9%	5.0%	26.6%
Chicago	Total Population			56.9%	19.6%	4.5%	17.2%
	> 2 km from a subway station	54.1%	66.1%	81.6%	10.6%	2.9%	3.3%
	≤ 2 km from a subway station	45.9%	33.9%	46.3%	38.7%	4.3%	8.6%
Philadelphia	Total Population			69.6%	20.1%	3.4%	5.1%
	> 2 km from a subway station	63.5%	69.5%	53.4%	25.0%	8.4%	9.9%
	≤ 2 km from a subway station	36.5%	30.5%	42.7%	36.9%	6.4%	11.1%
Washington	Total Population			50.2%	28.6%	7.7%	10.2%
Total US	Percentage of Total Population			69.1%	12.0%	3.6%	12.5%

- Chicago

The CTA's rapid rail network is composed exclusively of eight heavy rail lines, for most of the length the network is on elevated tracks or at grade. In Downtown Chicago, the Red and Blue Lines go into an underground subway, while the rest of the lines remaining on an elevated loop. A full third of the population of the Chicago Urban Area lived within 2 km of a subway station, and over 38% of all of the block groups are within the same distance. The population living in close proximity to the network is much more heavily minority than both the rest of the urban area and as compared to the national average – it is the only area included in this study where more than a quarter of the population living within 2 km or less of a subway station is Hispanic, and nearly 2/3 of that population is non-White.

Table III shows that in all of the cities under study, the median household income in block groups adjacent to rail transit is lower than in the urban area as a whole. The gap is most pronounced in Chicago, where the household median income in rail-adjacent neighborhoods is 78.3% of the urban area as a whole.

Table III

CITY		Rail-Adjacent Household Median Income	Urban Area Median Household Income	Difference
Boston	Mean	$49,131	$59,058	($9,927)
	σ^2	25209.91		
Chicago	Mean	$41,074	$52,454	($11,380)
	σ^2	19808.19		
Philadelphia	Mean	$37,685	$47,211	($9,526)
	σ^2	23038.44		
Washington	Mean	$58,297	$71,708	($13,410)
	σ^2	30048.4		
Total	Mean	$44,512	$55,525	($11,014)
	σ^2	24685.96	8306.281	

- Philadelphia

Philadelphia is unique among the cities in this study in several respects. It is the only city where there is more than one agency operating rail transit within the urban area. Southeastern Pennsylvania Transit Authority (SEPTA) runs three heavy rail lines and multiple light rail lines in Philadelphia proper and into the suburbs on the Pennsylvania side of the Delaware River. It is the only city in this study with an extensive amount of trackage that is street-running[24]. The Delaware River Port Authority runs the Port Authority Transit Corporation, PATCO, which operates a high speed heavy rail line from the New Jersey suburbs through Camden and into Center City Philadelphia. Transfers are possible between the two systems at 8th & Market, 12-13th and Locust, and 15-16th and Locust with the purchase of a ticket.

Philadelphia's subway network covers the largest number of block groups and the largest proportion of the total population of all of the cities in this study (45.9% and 33.9%, respectively). Like Chicago, more than half of the population living in close proximity to the subway is minority. While the demographic profile is not as markedly different between the area served by the subway network and the urban area as a whole, blacks and Hispanics in particular make up a much greater share of those in the service area than they do among the rest of the urban area's population.

- Washington

Washington's system mirrors Chicago's, being composed solely of five heavy rail rapid transit lines. Washington's network covers the District of Columbia, and many suburbs in both Maryland and Virginia. Of the networks included in this study, Washington's is the newest and has experienced the most growth over the past 50 years.[25]

The demographic mix of those living close to Washington's rapid rail system is closest to that of Chicago's, although Hispanics make up a much smaller share here than in Chicago. Economically, as can be seen from Table III, Washington residents in the urban area at large and those living adjacent to the rail system enjoy the highest household median incomes.

A notable feature of Washington, DC is the restriction put on construction within the District of Columbia under the Heights of Buildings Act, which limits the height of a building to no more than the width of the street or right of way that the building fronts. As a result, the average population density of the Washington area is 13,361 persons per square mile, as compared to 20,124 persons per square mile for the next lowest city, Philadelphia.

5. Results

Table IV shows the results of the regression across all four cities lumped together and then each city separately. The dependent variable is the log of rail transit users:

(All variables logged unless otherwise specified)	All Cities	Boston	Chicago	Philadelphia	Washington	Heavy Rail Only
Dependent Variable	Log of Rail Transit Commuters, Aged 16+					

Household Median Income	0.227***	0.103	0.361***	0.392***	0.124	0.239***
	(0.049)	(0.103)	(0.083)	(0.091)	(0.131)	(0.050)
Population Density	0.159***	0.173***	0.125**	0.165***	0.087*	0.161***
	(0.020)	(0.034)	(0.040)	(0.041)	(0.038)	(0.020)
Distance to Downtown (km)	0.732***	0.662***	0.785***	0.563***	0.497***	0.713***
	(0.058)	(0.084)	(0.168)	(0.120)	(0.133)	(0.059)
Distance to the Rail Station * Median Rooms Interaction Term	-0.183***	-0.078	-0.364***	-0.011	-0.112	-0.200***
	(0.029)	(0.077)	(0.068)	(0.048)	(0.086)	(0.031)
Total Bachelor Degree or Higher	0.270***	0.128**	0.344***	0.083*	0.227***	0.269***
	(0.019)	(0.049)	(0.031)	(0.036)	(0.052)	(0.020)
Median Rooms per Housing Unit	-0.07	-0.211	0.380*	-0.591***	0.082	-0.057
	(0.078)	(0.173)	(0.163)	(0.157)	(0.173)	(0.080)
Occupied Housing Units	0.159**	0.501***	0.266**	0.024	0.678***	0.155**
	(0.051)	(0.108)	(0.096)	(0.083)	(0.153)	(0.052)
Ages 15 to 24 and 65 and Older	-0.118**	0.211**	-0.284***	0.017	-0.277***	-0.119**
	(0.041)	(0.076)	(0.077)	(0.089)	(0.079)	(0.042)
Unemployed	0.019	-0.005	0.042	-0.015	0.04	0.014
	(0.017)	(0.030)	(0.031)	(0.034)	(0.038)	(0.018)
Commute Cost by Rail Transit	-1.377***	- 1.595***	-1.233***	-1.334***	-1.372***	-1.323***
	(0.130)	(0.247)	(0.359)	(0.259)	(0.299)	(0.134)
Median Contract Rent	0.137**	0.354***	0.074	-0.06	0.063	0.122*
	(0.047)	(0.086)	(0.086)	(0.105)	(0.093)	(0.047)
Total Households with No Cars	0.164***	0.043	0.196***	0.058	0.056	0.167***
	(0.024)	(0.050)	(0.044)	(0.054)	(0.041)	(0.025)
Total Females	0.285***	-0.055	0.212	0.386**	0.384*	0.291***
	(0.068)	(0.130)	(0.123)	(0.131)	(0.164)	(0.069)
Block Group with White, Non-Hispanic Majority (Dummy)	-0.137***	-0.088	-0.086	-0.026	-0.1	-0.148***
	(0.032)	(0.069)	(0.056)	(0.064)	(0.062)	(0.032)
Rail Transit Cheapest Mode of Tranist (Dummy)	0.056	0.069	0.583***	0.103	-0.011	0.066
	(0.052)	(0.081)	(0.172)	(0.118)	(0.075)	(0.054)
Light Rail is Nearest Transit Option (Dummy)	-0.170*	0.151		-0.111		
	(0.078)	(0.162)		(0.116)		
University (Dummy)	0.02	-0.156*	0.039	-0.099	0.016	0.019
	(0.026)	(0.063)	(0.043)	(0.059)	(0.051)	(0.026)
Chicago (Dummy)	-0.699***					-0.699***
	(0.041)					(0.042)
Philadelphia (Dummy)	-1.069***					-1.060***

	(0.043)					(0.044)
Washington (Dummy)	0.287***					0.293***
	(0.043)					(0.043)
Constant	-1.571**	-2.277*	-3.041***	-2.615*	-1.847	-1.593**
	(0.49)	(1.03)	(0.85)	(1.03)	(1.22)	(0.50)
Observations	4,126	811	1,584	1,080	651	3,962
p-value	0.000	0.000	0.000	0.000	0.000	0.000
R^2	0.663	0.612	0.657	0.258	0.719	0.659

All six iterations of the model are statistically significant ($p < 0.000$), but there is a wide gulf in the variation that the model captures from city to city. The R^2 goes as high as 71% for the Washington specification to a low of 26% for the Philadelphia specification. Several variables change signs between the two models, including ages 15-24 and 65 and older, the number of females, the indicator for light rail, and the indicator for the presence of a university.

The sign on household income is positive across all six cities, but is statistically significant across only four of the six specifications – all cities combined, Chicago, Philadelphia, and heavy rail transit only. The elasticity of demand on the commuter's cost of using rail transit across all four cities is within a tight range of about 0.45. The average of all four cities is -1.377, reflecting a good whose demand is relatively elastic. Further, the positive sign on median contract rent for all cities but Philadelphia confirms the intuition of the monocentric city model. Commuters are making trade-offs between transit cost (including time), and their housing space, *s*, net of income. This implies that as the median rent rises, the propensity to use public transit would increase due to the fact that for most of the geography under study, rail is the least costly option available. A caveat is that the statistical significance of this variable seems to be driven by observations from Boston – removing Boston from the regression causes median contract rent to retain its positive sign, but it is no longer statistically significant.

All else being equal, a 1% increase in households who were not car owners, population density, the distance from downtown, in the number of people who are not likely to be students or retired (greater than 24 and less than 65), and had white, non-Hispanic majorities would lead to an increase in the number of commuters who choose rail transit. The positive sign on the distance from downtown is unexpected. This could be capturing the fact that commuters who are relatively distant from the city center are sensitive to the increased cost of gasoline incurred by driving. Further, while the model controlled for rush hour speeds of commute, it does not factor in the costs associated with the probability of a traffic jam. Commuters living furthest away from the CBD would be especially sensitive to this cost. Also unexpected was the negative sign on the indicator for a minority-majority block group. This could be due to the fact that even when accounting for the unemployment rate, persistent discrimination against minorities makes it more difficult to secure employment in the CBD. The statistical significance of the city dummies suggests that there are unique conditions to each system and city that have a strong influence on the ridership in each census block group. Relative to an observationally similar block group in the omitted category of Boston, a census block group in Philadelphia is likely to have a 1.06% lower incidence of rail transit usage.

In fact, Philadelphia stands out from the other cities in the model very prominently. This could be because Philadelphia's system is markedly different from the other three cities systems in several ways. One is that it is actually composed of two agencies, SEPTA and PATCO – PATCO serves Center City Philadelphia and the New Jersey suburbs of Philadelphia, where as SEPTA's rail system covers Philadelphia and the Pennsylvanian suburbs. Secondly, a large portion of its light rail system is composed of trolleys that run through the middle of the street[26], without the benefit of a median (such as in most of the Boston Green Line system) or any other form of dedicated right of way. This means in effect that while they run towards the CBD, they do not offer any form of advantage over a bus or even a car in terms of avoiding traffic. Lastly, Philadelphia has three long rail lines that spoke out from the 69th Street Terminal just outside Philadelphia proper. Passengers wanting to commute to the CBD by rail from a point near these lines would have to ride them all the way to the 69th Street Terminal and transfer to the Market Street-Frankford Line before heading to Center City Philadelphia. Philadelphia is the only city under consideration where more than one rail segment does not go as a "one seat" ride to the CBD.[27]

6. Conclusion/Discussion

The results from this study indicate that the traditional hypothesis for the relationship between public transit and income perhaps bears some revision. The relationship was positive across all geographies, but was not statistically significant in Boston or Washington. Notably, these cities have seen growth in the size of their rail networks since 1970, a time period where previous research has indicated that poorer census tracts were more likely to see new rail lines than wealthier ones. Glaeser , Kahn, and Rappoport (2006) strongly suggest that including cities such as Atlanta and Los Angeles, which were not large cities in 1900, and therefore less mass transit oriented, would likely weaken this result.

Further research on this topic could determine if a positive income elasticity of demand for rail transit would exist under a polycentric model. One explanation for the positive correlation between rail transit and income is that higher paying, white collar jobs tend to cluster in the downtown area. In a polycentric model, where rail transit could serve less dense employment clusters, this correlation might weaken or disappear. Similarly, commuters may travel to different employment nodes in the CBD and outside of it by a combination of rail and other modes. The design of this study is intended to be able to reasonably ignore the impact of "park and ride" and commuting by bus within the defined geography. Yet, a more global measure of the true income elasticity of demand would include commuters who change from cars to subways or from buses to subways.

An important weakness of this model is that it is not sensitive to discrepancies in how different commuters value time. If, as seems likely, wealthy commuters value their time more highly than poorer commuters, then two responses seem likely. The first is that these wealthier commuters would want to live closer to their jobs, making public transit or walking a more attractive option. The second is that they would put a higher premium on faster modes of commute, which would favor automobiles. These two responses pull the model in different directions, and quantifying which method commuters choose to lessen the time spent in commute could have significant implications for the income elasticity of demand for rail transit. This is an especially salient question, in light of the fact that Glaeser, Kahn, and Rappoport (2006) found that the per mile time cost of rail transit is higher than it is for cars.

The monocentric city model provides one possible answer. One factor not adequately addressed by this study is the role of the age of the city and the usage of public transport. Glaeser, Kahn, and Rappoport (2006), Anas, Arnott, and Small (1998), and Poulton (1980) demonstrate that there are important structural differences in terms of transit in "newer" cities, such as Los Angeles, and older ones, such as Boston and Chicago, that in part seems to be related in a difference in the role of income in how commuters spatially distribute themselves. Spacious homes tended to be built within driving distance of downtown in newer cities, whereas older cities tend to have clusters of spacious homes adjacent to the CBD. Notably, of the four cities included in this study, Washington has many similar aspects to a city such as Los Angeles, in that both have relatively new subway system and have relatively lower population densities. It is probably not a coincidence therefore that Washington has the lowest reported value for the income elasticity of demand.

Lastly, the results of this paper likely underestimate the cost of commuting by car by not including measures for the high fixed cost of owning a private vehicle. Where it is easy and convenient to have access to rail transit, the high fixed cost of car ownership may cause people to self-select to live near a rail line, thus biasing the result.

From a public policy perspective, building additional rail transit as a means of enabling greater mobility among poorer populations might be misguided. This research suggests that in fact rail transit seems to be more attractive to somewhat richer populations. Yet, these results also suggest that rail transit as a policy tool can be used by the same token to take many middle class commuters off of the road. As the case for environmentally-friendly policies continues to build steam, rail transit by the evidence seems to be a method of transit favored by those populations most likely to own and use a car. Making rail transit more available to them could both be economically beneficial in the ways outlined by Voith (2005), but also environmentally beneficial by reducing automobile usage.

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[2] *E.g.*, Schenker and Wilson (1967), Holmgren (2007)

[3] *E.g.* Dajani, Egan, McElroy (1975), Schmenner (1976), Baum-Snow, Kahn, and Voith (2005), Glaeser, Kahn, and Rappaport (2006).

[4] *See* Rothenberg Pack (1992) for a discussion of the benefits of government rail transit subsidies. As noted in the Data section, all of the agencies that run the transit systems used in this study are government owned, operated, and subsidized.

[5] Brookline, Massachusetts is an excellent example of this phenomenon. Initially, it was settled as a summer get- away from Boston for the wealthy. With the construction of a streetcar line running through the median of Beacon Street, it rapidly urbanized. Today, the Beacon Street line is the "C" Branch of the Boston Green Line. Many turn of the century apartment buildings abut directly onto Beacon Street, but on the side streets right off of the main line are many large, single-family homes.

[6] Gordon and Richardson (1996) have declared that Los Angeles, is in fact, "beyond polycentricity".

[7] This topic was raised even earlier in a study of U.S. cities in a paper by Woodbury (1931).

[8] \$13.00 versus \$13.47 as a national average according to the 2001 Colliers Survey, which includes many cities such as Indianapolis, IN and Bakersfield, CA with no rail transit.

[9] Voith (1995)

[10] For greater information about the Monocentric City Model, see Alonso (1965), Muth (1969), and Mills (1972)

[11] Dewees (1979) found that commuters weight the time they spend walking to a rail station and waiting for a train more heavily than they do being on transit. In consideration of this finding, half of the highest observed rush hour headway was used for the waiting time.

[12] Bicycles are another alternative to both cars and public transit, but they are excluded from this model for the sake of simplicity. Across all four cities, less than 1% of all commuters within the 2 kilometer zone of a subway stop commuted to work by bicycle.

[13] This graph was created from STATA's two-way linear prediction plotting command ("graph twoway lfit"). Each line represents the average of each parameter in the equations elaborated in the theoretical model, with only distance from the CBD allowed to vary independently.

[14] Dewees (1979) found that streetcar service often operates at lower speeds than rail on a dedicated right of way. Empirical evidence from the transit agencies confirms that intuition. However, his study also found that it was inconclusive as to whether the presence of heavy rail

over light rail was a net benefit to all commuters, due in part to heavy rail systems greater distances between stations.

[15] This graph was created from STATA's two-way quadratic prediction plotting command ("graph twoway qfit").

[16] Los Angeles nominally falls under the category of inclusion here, but in the year 2000, the Purple Line was only considered a branch of the Red Line. Further, the Purple Line only differs from the Red Line by two stops. Thus, for the purposes of this study, Los Angeles is only considered to have one heavy rail rapid transit line.

[17] Atlanta was similarly excluded, because although there are officially four subway lines, the Blue and Green lines differ only by one stop; the Red and Gold lines differ by only three each, as by June 2000, the Sandy Springs and North Springs stations had not been completed.

[18] San Francisco was excluded here because the BART system runs through both San Francisco and Oakland, suggesting strongly that the system serves a polycentric city. New York was excluded due to the fact that it also was a polycentric city, with significant business districts in Midtown and Downtown Manhattan and sections of Brooklyn. Further, the PATH heavy rail line system allows New York City residents to easily commute to Newark's CBD, creating further confusion.

[19] Google Maps, www.septa.org, www.mbta.com, www.wmata.com, www.transitchicago.com/, http://www.ridepatco.org/

[20] http://stevemorse.org/jcal/latlonbatch.html?direction=forward

[21] For example, if the travel time to Downtown Chicago was 20 minutes from a given block group according to Google Maps during non-peak times, then with a Travel Time Index factor of 1.33, then during rush hour, a commute could expect the same trip to take 26.6 minutes.

[22] The Transportation Mobility Institute updates their information from industry and logistical data. Sources cited are: McFarland, W.F. M. Chui. (1987). The Value of Travel Time: New Estimates Developed Using a
Speed Choice Model." Transportation Research Record N. 1116, Transportation Research Board, Washington, D.C. and Ellis, D. (2009). Cost Per Hour and Value of Time Calculations for Passenger Vehicles and Commercial Trucks for Use in the Urban Mobility Report. Texas Transportation Institute.

[23] This chiefly affects the classification of SEPTA's Norristown High Speed Rail Line and the "D" Branch of Boston Green Line, both of which have fully dedicated right of ways. Internally, it appears that SEPTA also classifies this line as heavy rail (http://www.septa.org/reports/pdf/strategic.pdf, p. 4).

[24] A small portion (0.7 miles) of Boston's Green Line on the "E" Branch runs in the middle of Huntington Avenue in the Jamaica Plain neighborhood without the benefit of a median or a separated right of way.

[25] http://www.wmata.com/about_metro/docs/history.pdf

[26] Subway-Surface Trolleys, Lines 10, 11, 13, 34, 36, 101, and 102.

[27] The only two other lines that do not feature a one seat ride are the Skokie Swift in Chicago (one line, two stops), and the Ashmont-Mattapan trolley in Boston.