POLICY RESEARCH WORKING PAPER 3007

The Impact of Urban Spatial Structure on Travel Demand in the United States

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Development Research Group
Infrastructure and Environment
March 2003

Abstract

Bento, Cropper, Mobarak, and Vinha combine measures of urban form and public transit supply for 114 urbanized areas with the 1990 Nationwide Personal Transportation Survey to address two questions: (1) How do measures of urban form, including city shape, road density, the spatial distribution of population, and jobs-housing balance affect the annual miles driven and commute mode choices of U.S. households? (2) How does the supply of public transportation (annual route miles supplied and availability of transit stops) affect miles driven and commute mode choice?

The authors find that jobs-housing balance, population centrality, and rail miles supplied significantly reduce the probability of driving to work in cities with some rail transit. Population centrality and jobs-housing balance have a significant impact on annual household vehicle miles traveled (VMT), as do city shape, road density, and (in rail cities) annual rail route miles supplied. The elasticity of VMT with respect to each variable is small, on the order of 0.10–0.20 in absolute value. However, changing several measures of form simultaneously can reduce annual VMT significantly. Moving the sample households from a city with the characteristics of Atlanta to a city with the characteristics of Boston reduces annual VMT by 25 percent.

This paper—a product of Infrastructure and Environment, Development Research Group—is part of a larger effort in the group to examine factors affecting travel behavior. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Viktor Soukhanov, room MC2-521, telephone 202-473-5721, fax 202-522-3230, email address vsoukhanov@worldbank.org. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. Maureen Cropper may be contacted at mcropper@worldbank.org. March 2003. (54 pages)

THE IMPACT OF URBAN SPATIAL STRUCTURE ON TRAVEL DEMAND IN THE UNITED STATES

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We would like to thank Richard Arnott, Matthew Kahn, Jordan Rappaport, Ken Small, Margaret Walls, and participants at seminars at Columbia University, Stanford University, University of California, Berkeley, the NBER Summer Institute July 2001, ASSA Meetings January 2002, World Congress of Environmental and Resource Economists 2002, and Colorado Environmental and Resource Economics Workshop 2002.

I. Introduction

A. Motivation and Purpose

Since the Second World War the predominant pattern of urban growth in the United States has been one of low density development and employment decentralization, accompanied by a rapid increase in automobile ownership and vehicle miles traveled (Mills 1992, Mieszkowski and Mills 1993, Glaeser and Kahn 2001). The last 15 years, however, have witnessed a reaction to urban sprawl in the form of "smart growth" initiatives.[1] Attempts to limit urban growth or to change its form are motivated by three concerns—to preserve open space and foster urban development that is more aesthetically appealing, to reduce the cost of providing public services, and to reduce dependence on the automobile and the externalities associated with automobile use—especially air pollution and congestion—that have accompanied urban sprawl.[2]

This naturally raises the question: how does urban form—whether measured by the spatial distribution of population or employment or the public transit network—affect vehicle ownership and the number of miles driven by households in the United States? This paper attempts to shed light on this question by combining measures of urban form and transit supply in 114 urbanized areas in the U.S. with data from the 1990 Nationwide Personal Transportation Survey. We ask whether measures of urban sprawl—measures that describe city shape, the spatial distribution of population and jobs-housing balance—and the supply of public transit affect the annual miles driven and commute mode choices of U.S. households. In the case of

[1] Urban Growth Boundaries, which have been established by 70 cities in California, are the most popular instrument to combat sprawl under the smart growth initiatives. See Glickfeld and Levine (1992), Levine (1999) and Fulton, Shigley, Harrison and Sezzi (2000) for surveys.

[2] For a discussion of the impacts of these externalities on urban spatial structure see Brueckner (2001) and Bento and Franco (2002). Kahn (2000) discusses the environmental impacts of suburbanization.

public transit we are interested both in the extent of the transit network city-wide and also in the proximity of transit to people's homes (distance to the nearest transit stop).

Previous attempts to answer these questions have relied either on city-level observations or on studies of household data in which measures of urban form are endogenous. City-level studies that correlate measures of automobile use with population density or density gradients (Newman and Kenworthy 1989, Levinson and Kumar 1997, Malpezzi 1999) often fail to control for other variables that affect automobile ownership and mode choice. Analyses of vehicle ownership and miles traveled using household data often include measures of urban form, but ones that are clearly subject to household choice. For example, the population density of the census tract or zip code in which the household lives is often used as a measure of urban sprawl (Train 1986; Boarnet and Crane 2001; Levinson and Kumar 1997), and the distance of a household's residence from public transit or from the CBD as a measure of availability of public transportation (Boarnet and Sarmiento 1998, Boarnet and Crane 2001, Train 1980).[3] Coefficient estimates obtained in these studies are likely to be biased if people who dislike driving locate in areas where public transit is more likely to be provided.

B. Approach Taken

We address these issues by adding city-wide measures of sprawl and transit availability to the 1990 Nationwide Personal Transportation Survey (NPTS). The survey contains information on automobile ownership and annual miles driven for over 20,000 U.S. households. It also contains information on the commuting behavior of workers within these households. For NPTS households living in the urbanized portion of 114 Metropolitan Statistical Areas (MSAs)[4] we construct measures of urban form—measures of city shape (how close to circular the city is)

[3] For a review of the literature, see Badoe and Miller (2000).

[4] We use the 1990 boundaries of urbanized areas associated with the 114 metropolitan areas in our study. These boundaries are defined by the U.S. Census Bureau. Urbanized areas are those that have a population density that is greater than 1,000 people per square mile and a total population of at least 50,000.

and the density of the road network, measures of the spatial distribution of population (how close to the CBD the population is located) and of jobs-housing balance. To characterize the transport network we compute city-wide measures of transit supply—specifically, bus route miles supplied and rail route miles supplied, normalized by city area. In addition to using city-wide measures of sprawl and transit availability, we address the endogeneity of "proximity to public transit" by instrumenting the actual distance of the household to the nearest transit stop using the average usage of transit in the potential residential choice set of census tracks in an urban area.

We use these data to estimate two sets of models. The first is a model of commute mode choice (McFadden 1974), in which we distinguish four alternatives—driving, walking/bicycling, commuting by bus and commuting by rail. We estimate this model using workers from the NPTS who live in one of the 26 cities in the U.S. that have some form of rail transit, as well as data on our other measures of urban form. The second set of models explains the number of vehicles owned by households and miles driven per vehicle. These are estimated using the 8,297 households in the NPTS who have complete vehicle data and who live in one of the 114 urbanized areas for which we have both sprawl and transit data.

C. Results

Our results suggest that individual measures of urban form and public transit supply have a small but statistically significant impact on travel demand. In the case of commute mode choice, a 10% increase in population centrality lowers the chance that a worker drives to work by 2.1 percentage points; a 10% increase in distance to the nearest transit stop raises the chances of driving by 1.6 percentage points. These effects, however, are only half as large when New York is dropped from our sample of cities. The impacts of increasing rail or bus route miles (with or without New York) are smaller than the impacts of population centrality and distance to the nearest transit stop. These results suggest that attempts to reduce auto dependence by altering urban form and increasing the supply of public transit are likely to have modest effects.

Urban form and transit supply affect annual miles driven both by influencing the number of cars owned and miles traveled per vehicle. In cities where the spatial distribution of population is more compact and where public transit is more available (as measured by the instrumented distance to the nearest transit stop), households are less likely to own a car. The quantitative impact of these variables on annual average VMTs is, however small: a 10% increase in population centrality, through its effect on vehicle choice, reduces annual VMTs by only 1.5%, while a 10% increase in distance to the nearest transit stop increases VMTs by about 1%. Other measures of urban form and transit supply—jobs-housing balance, road density, city shape and the supply of rail transit—all affect average miles driven per vehicle but not the number of vehicles owned. A 10% increase in road density increases annual VMTs by 0.7% while a 10% increase in the index that indicates how circular a city is reduces annual VMTs by 0.4%. In cities with a rail system, a 10% increase in rail route miles reduces annual VMTs by 0.2%.

Programs to alter urban form are, however, likely to affect more than one measure of sprawl and transit availability simultaneously. To examine the potential for such measures we move our sample households from a city with measures of urban form and transit supply identical to those of Atlanta to a city with measures the same as those of Boston. The net effect is to reduce annual VMTs by 25%.

The rest of the paper is organized as follows. Section II reviews the relationship between urban form and travel demand in the urban economics literature, describes our empirical measures of urban form, and compares these measures with traditional sprawl measures. It also describes our city-wide transit variables and as well as our instrument for proximity to pubic transportation. Section III presents the results of our commute mode choice models, and section IV our models of automobile ownership and VMTs. Section V concludes.

II. The Relationship Between Urban Form and Travel Demand

A. Theory

Urban Economics predicts that the number of miles a household travels and the mode it chooses for different trips will depend on the structure of the city in which the household resides—on the distribution of population and employment within the city, on the size of the city (in sq. miles), and on its road and transit networks.

In the simple monocentric model (Muth 1969) in which all employment is located in the CBD and the number of trips per worker is fixed, the number of miles a household travels is proportional to how far from the CBD it locates (τ). This depends on the rent gradient it faces, $r(t)$, and on the marginal cost of travel, which, in general, varies with distance, t, from the CBD. To allow for congestion, Wheaton (1998) suggests that the marginal time cost of travel, $c(t)$, varies directly with population density at t, $n(t)/2\pi t$, where $n(t)$ is population at distance t, and inversely with the proportion of land devoted to roads at t, $v(t)$. The household's travel demand, which equals the number of one-way trips to the CBD times τ, thus depends (through choice of τ) on the road network, $v(t)$, and on the distribution of population throughout the city, $n(t)$.

The conclusion that travel depends on urban form continues to hold if the monocentric model is modified by introducing public transportation, allowing employment to be located throughout the city and including non-work trips. Suppose, following White (1988), that the household worker is employed at distance k from the CBD. Assume he works h hours per day and L days per period at a daily wage of w. Commute trips are made either by driving ($I_w = 1$) or by taking public transit ($I_w = 0$). Assume that household utility depends on land consumed, q, on a vector of consumption goods, X, and on miles traveled by auto (M) and public transit (N) each period. Each good purchased, x_i, has three costs associated with it: a dollar cost, p'_i; a time cost, t'_i; and a distance that must be traveled in order to purchase the good, d_i. The cost of traveling d_i depends on the household's residential location τ and on the travel mode.[5] Let I_i = 1 if the household drives to purchase good i; $I_i = 0$ if public transit is used.

Urban form and transit supply influence the household's mode choice and total miles driven in several ways. The marginal time cost of each trip made by auto depends, as in Wheaton (1998), on population density and the proportion of space devoted to roads at each t, $c(t) = n(t)/2\pi tv(t)$. Likewise the frequency of transit service, number of transit stops and route miles supplied will influence the marginal time cost of traveling by public transit at location t, $b(t)$. The distance that the household must travel to purchase good i (d_i) depends on how far it lives from the CBD, and on population (i.e., the size of the market) where it resides. Formally, $d_i = d_i(\tau, n(\tau))$.

The household selects its location, τ, the amount of land it will purchase, q, a vector of consumption goods, X, and its travel mode for all trips $\{I_w, I_i\}$ to maximize utility

(1) $U(q,X,M,N)$

subject to time and budget constraints

(2) $T = L(h + t_L) + \Sigma\, t_i x_i$

(3) $(w-c_L)L = r(\tau)q + \Sigma\, p_i x_i$

where

$p_i = p'_i + d_i\,[\varphi I_i + \phi(1-I_i)]$

[5] We assume that the direction of travel is always toward the CBD and that one unit of good i is the amount that would normally be purchased on a single trip (e.g., a restaurant meal or bundle of groceries).

$$t_i = t'_i + [(1-I_i) \int_{\tau-d_i}^{\tau} b(t)dt + I_i \int_{\tau-d_i}^{\tau} c(t)dt]$$

$$c_L = (\tau-k) [\varphi I_w + \phi(1-I_w)]$$

$$t_L = (1-I_w) \int_{k}^{\tau} b(t)dt + I_w \int_{k}^{\tau} c(t)dt$$

$$0.5M = \Sigma x_i d_i I_i + LI_w(\tau-k)$$

$$0.5N = \Sigma x_i d_i (1-I_i) + L(1-I_w)(\tau-k).$$

In equations (2) and (3) φ is the roundtrip dollar cost per mile driven and ϕ the roundtrip cost per mile of public transit. $c(t)$ and $b(t)$ are roundtrip time costs. t_L is daily commute time and c_L is daily commute cost. p_i is the total out-of-pocket cost of each unit of good i (including the dollar travel cost) and t_i is the total time cost of purchasing and consuming a unit of i.

One can think of the household maximizing utility by choosing the optimal quantities of land, purchased goods and travel modes conditional on location, and then choosing the location τ that yields the highest utility. Once τ is chosen, commute mode (I_w) and miles driven (M) can be expressed as functions of the characteristics of urban form and the transit network that are exogenous to the individual household; specifically, (1) the road network, $v(t)$; (2) the pattern of residential land use, $n(t)$; (3) the time cost of travel on public transit, $b(t)$, which, in turn, depends on the extent of the transit network, frequency of service, etc.; (4) out-of-pocket costs of travel by auto and travel by public transit, and (5) the distribution of employment throughout the city, which affects k.

B. Measures of Urban Form

The model in the previous section suggests that vehicle miles traveled and commute mode choice depend on three aspects of urban form—the road network, the pattern of residential land use, and the distribution of employment, which is also a proxy for the distribution of services, throughout the urbanized area. How should these dimensions of urban form be measured empirically? Our choice among alternate measures of each dimension of urban form is guided by two principles: the set of measures should capture different aspects of urban form (i.e., they should not be too highly correlated with each other), and, to facilitate interpreting our results, it should be possible, conceptually, to vary one measure while holding the others constant.

Road Network

A complete description of the road network in a circular city would include describing road density in successive annuli around the CBD, as well as the pattern of roads (e.g., a radial network with or without ring roads). The situation is more complicated in a city that is not radially symmetric. We use two measures to describe the road network. The first is a measure of *city shape*. The second is a measure of *average road density* for the urban area.

City Shape. Theory suggests that trip distances should be longer in long, narrow cities than in circular cities with radial road networks. To measure how much an urbanized area deviates from a circular city we have circumscribed each city with an ellipse equal in area to the urbanized area of the city, and have measured the major and minor axis of the ellipse. The ratio of the minor to the major axis is our measure of city shape. It ranges between 0 and 1, with 1 indicating a circular city.[6]

[6] See the Data Appendix for a more complete description of the measures.

Road Density. For each urban area, miles of road are multiplied by average road width (for different categories of road) divided by the size of the urbanized area (in km^2).

Pattern of Residential Land Use

In a circular city the natural measure of the pattern of residential land use is the population density gradient (McDonald 1989). The density gradient describes the centralization of population around the CBD. The density gradient, together with the city radius (or city area) and the intercept of the density function, completely describe the distribution of population within a monocentric city. An alternative to the density gradient as a measure of centrality is the percent of population living at various distances (e.g., within 5 km, within 10 km, etc.) from the Central Business District (CBD) (Glaeser and Kahn 2001). Both measures of course require that one identify a single CBD. The population density gradient is the more restrictive of the two measures as the conventional negative exponential gradient assumes that density declines monotonically with distance from the CBD. Because of the poor fit of exponential density gradients in many cities (Malpezzi 1999) we reject the population density gradient as a measure of population distribution. We also reject as a measure of decentralization the percent of population living within 5 km, 10 km, 15 km and 20 km of the CBD. The correlation among these measures and between each measure and city area violated our criterion that different measures of urban form not be too highly correlated.[7]

Population Centrality. To create a measure of population centrality that is less correlated with city area, we plot the percent of population living within x percent of the distance from the CBD to edge of the urbanized area against x and compute the area between this curve and a 45-

[7] The correlation coefficients between land area and percent of the population living within various distances from the CBD are are follows: 5 km (-0.61), 10 km (-0.66), 15 km (-0.73), 20 km (-0.73). We also computed similar measures for cities with multiple CBDs, where distances were measured from a point equidistant from the CBDs. These measures, too, were highly correlated with city area.

degree line representing a uniformly distributed population.[8] We term this our measure of *population centrality.*[9] Higher values of population centrality indicate that a larger fraction of the population lives near the CBD. Since our *population centrality* measure does not capture city size, we supplement this with the size of the urbanized area in square miles.

Distribution of Employment

The set of possible employment locations in an urban area clearly affects commute lengths, τ-k. Similarly, the distribution of employment in commercial and retail occupations, relative to the distribution of residences, is likely to affect distance traveled for non-work trips. There are several ways in which the distribution of employment could be measured. One is a measure of employment centrality similar to our measures of population centrality; another is the employment density gradient. We believe, however, that for studying the determinants of driving behavior, it is more important to measure the location of employment relative to population, or jobs-housing balance. To measure the spatial balance of jobs versus housing we have borrowed a measure from the residential segregation literature (Massey and Denton 1988), which we compute using employment data from *1990 Zip Code Business Patterns* (U.S. Census Bureau).[10]

Imbalance of Jobs v. Housing. To measure how evenly jobs are distributed relative to population we order zip codes in each city from the one having the smallest number of jobs to the one having the largest and plot the cumulative percent of jobs (y-axis) against cumulative

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[8] The locations of the CBDs are given by the *1982 Economic Censuses Geographic Reference Manual*, which identifies the CBDs by tract number. For polycentric cities, we have computed this measure in reference to the main CBD.

[9] The area between the Lorenz curve and the 45-degree line is normalized by dividing by the area above the 45-degree line. Population centrality thus varies between 0.0 and 0.5.

[10] We also computed the average weighted distance of jobs from housing in each urban area Galster et al.'s (2000) proximity measure, originally proposed by White (1986); however, it was very highly correlated with city area (r=0.80).

percent of population (x-axis) to obtain a Lorenz curve. The 45-degree line represents an even distribution of jobs v. population. Our *imbalance* measure (Massey and Denton's Gini coefficient) is the area between the Lorenz curve and the 45-degree line, expressed as a proportion of the area under the 45-degree line. Larger values of this measure imply a less even distribution of jobs v. housing.

How different are our measures from traditional measures of urban sprawl? Urban sprawl is most often measured using average population density in a metropolitan area. Average population density is clearly a blunt measure of sprawl, and is only weakly correlated with population centrality ($r = .16$), jobs-housing imbalance ($r = .06$) or city shape ($r = -.10$). Table 1 further illustrates the fact that population centrality and jobs-housing imbalance capture different aspects of sprawl than average population density.[11] Using a rank of "1" to indicate the least sprawled urbanized area in our sample, Table 1 compares the rankings of the 13 most densely populated cities in our sample based on our measures of sprawl against rankings based on population density. The New York urbanized area (which includes Northern NJ and Long Island) is, not surprisingly, the 3rd least sprawled urbanized area based on population density. It is also the 5th least sprawled city based on population centrality; however, it is the 95th least sprawled city in terms of jobs-housing balance and the 92nd least sprawled in terms of road density. San Diego, which is the 13th most densely populated city in our sample, is the most sprawled city in terms of job-housing imbalance. Miami, the second most densely populated city in the sample, is the least circular city. The table thus illustrates the fact that our measures capture dimensions of urban structure that are missing in the population density measure.

[11] Appendix B presents summary statistics for sprawl and transit variables for all cities in our sample.

C. Measures of Transit Supply

Reliance on public transportation, whether for commute or non-commute trips, depends on both the extent of the transit network and the proximity of transit stops to housing and work locations. We measure the extent of the public transport network by the number of bus route miles supplied in 1993, divided by the size of the urbanized area (in km^2), and by the number of rail route miles supplied in 1993, divided by the size of the urbanized area.[12]

In other travel demand studies, proximity to public transportation is usually measured by a household's distance to the nearest transit stop (Baum-Snow and Kahn 2000; Walls, Harrington and Krupnick 2000). This measure is likely to overstate (in absolute value) the impact of transit availability on mode choice since households that plan to use public transit frequently will locate near bus and metro stops. Since the problem here is endogeneity of location choice, we construct an instrument which attempts to measure the average transit availability across the entire set of zip codes where the household *could* have located before the actual location choice is made.[13] For each household we identify the set of census tracts where the household could afford to live in the city in which it currently lives. This is the set of tracts that have median household income, based on 1990 Census data, less than or equal to the household's own income *or* to the median income of the zip code in which the household currently lives.[14] Unfortunately we cannot measure the number of transit stops in each census tract. What we can measure is the percent of people in each tract who usually rode public transportation to work in 1990. We average this number across all tracts that household i can

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[12] Rail (bus) route miles represent the number of miles traveled by all railroad cars (buses) during a year.

[13] This instrument does not solve the potential endogeneity of households choosing the metropolitan area in which to locate based on the availability of transit in that city. However, according to the U.S. Census *Current Population Survey*, Americans are over four times more likely to be migrating within the same county or same state than across state boundaries. In practice, the endogeneity of city choice is therefore much less of an issue.

[14] Residential location is known only at the zip code level (rather than the census tract) in the 1990 NPTS.

afford. Our instrument is obtained by regressing household *i*'s distance to the nearest transit stop on the average transit usage variable.

Table 2 presents summary statistics for our sprawl and transit measures for the 114 cities in our sample and Table 3 the pairwise correlations between the sprawl and transit measures. Not surprisingly, our measures of transit supply are correlated with each other, as well as with measures of urban form. Cities that are larger in area and more densely populated tend to have a greater supply of both rail and bus transit. The supply of non-rail transit is twice as great in the 26 rail cities in our sample as in the other 86 cities, suggesting an attempt to link rail and bus networks. Average distance to the nearest transit stop (as originally reported and in instrumented form) is lower in rail than in non-rail cities and is highly negatively correlated with bus route miles supplied (r = -0.50). Higher road density is also correlated (r = 0.39) with greater supply of bus transit; however, population centrality, jobs-housing imbalance and city shape are not highly correlated with public transit supply or with road density.

III. Commute Mode Choice Models

Although commuting trips account for only one-third of miles driven by households in urban areas, they contribute disproportionately to congestion and air pollution, and, consequently, are often the focus of studies of travel demand.[15] In this section we link the measures of urban form and transit supply described in the previous section to the 1990 Nationwide Personal Transportation Survey (1990) to explain the "usual mode" of commute to work of workers living in cities with some rail transit. Specifically, we estimate multinomial logit models of mode choice in which workers choose among (a) driving to work, (b) taking rail transit, (c) taking non-rail transit or (d) walking or bicycling.

[15] The NPTS day trip file gives the following breakdown of the miles driven by households: 34% commuting; 19% family business; 14% recreation; 12% visiting family and friends; 11% shopping; 5% going to school or church; 2%

A. A Model of Commute Mode Choice

Our empirical model of commute mode choice may be derived from the model of section II as follows. Suppose the worker chooses his optimal location and non-work travel, as well as his consumption of land and other goods, conditional on commute mode. Substituting the optimal values of these variables as functions of prices, income, measures of urban form and transit availability (which influence $c(t)$, $b(t)$ and τ) into equation (1) yields an indirect utility function conditional on commute mode. The worker chooses the commute mode yielding the highest conditional indirect utility.

The empirical counterpart to the choice of commute mode is a random utility model in which the observable component of indirect utility from commute mode w for household i (V_{iw}) depends on income, travel costs (φ and ϕ), on measures of urban form and transit availability and on worker and household characteristics that influence utility. Assuming that the unobservable component of the utility of mode w to household i, u_{iw}, is independently and identically distributed for all i and w with a Type I Extreme Value distribution yields a multinomial logit model of commute mode choice. We include in V_{iw} the age, race, education and gender of the worker, number of adults and children in the household, and household income. The variable cost per mile of driving is calculated as the city-specific gasoline price, divided by the average fuel efficiency of cars owned by households in the same income class as the commuter (see Appendix C for details). Data on the price of rail or bus trips were available for too few cities to make this variable usable. Also included in V_{iw} are the measures of urban form and transit supply in Table 2, as well as average annual rainfall and snowfall, which may influence commute mode choice.

work related business; and less than 2% for each of the following categories: vacation, visiting a doctor or a dentist,

B. The NPTS Worker Sample

The 1990 NPTS consists of 22,317 households living in urban and rural areas of the US. 9,719 of these households lived in the 114 urbanized areas for which we have data on both sprawl and transport measures. These households constitute our core sample. To obtain significant variation in commute mode choice, we focus on the 26 cities with some rail transit. The 6,470 workers in our sample households in these cities are used to estimate the commute mode choice model. We distinguish four usual commute modes—private transportation, non-rail transit, rail transit and non-motorized transit. Table 4 shows the percent of workers using each mode. The percent of workers using private transport (79.7%) is lower than the average for all workers in the NPTS (86.5%). This is because workers in the New York urbanized area constitute approximately 30% of our sample. As the table shows, the percent of commuters in rail cities who drive to work is approximately equal to the NPTS average when the New York urbanized area is removed from the sample. Approximately 6% of our sample commute by bus (5% without NY) and 8% by rail (2% without NY), while approximately 6% either bike or walk to work (with or without NY).

Table 4 also presents mean respondent characteristics by usual commute mode. Bus riders have significantly lower incomes, on average, than people who drive or take the train to work. They also have significantly less education and are more likely to be black than workers who drive or walk to work. The racial differences across transit modes are indeed striking: whereas 81% of persons who drive to work are white, only 50% percent of bus riders are white (48% excluding NY). Rail riders have significantly more education than persons who drive to work, but have fewer children. The last row of the table suggests that riders of public transit

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pleasure driving, or for other reasons.

self-select to live near public transit. The average distance to the nearest transit stop is 2-3 blocks for rail and bus riders, but over 12 blocks for commuters who drive.

C. Commute Mode Choice Results

Results for our commute mode choice equations appear in Table 5. In both models the omitted mode is driving to work; hence all coefficients should be interpreted relative to this category. The table displays the coefficient of each explanatory variable for each mode, the ratio of the coefficient to its standard error, and the marginal effect of significant variables on the probability of selecting each mode.[16] For continuous variables, marginal effects are also expressed as elasticities. Because workers in the New York urbanized area constitute such a large fraction of our sample, we present results with and without New York.

The effects of household characteristics on commute mode choice largely mirror Table 4. Income, race and education all have statistically significant impacts on the probability that a commuter takes transit or walks to work. In both samples higher income workers are less likely to walk to work or take public transit than they are to drive. The income elasticity of bus, rail and non-motorized modes are well below one in absolute value in the full sample (-0.5, -0.1, -0.3, respectively), a result similar to McFadden (1974). The elasticities are somewhat higher when New York is removed from the sample: -0.6, -0.9 and -0.5, for bus, rail and walking, respectively. Blacks are more likely to walk or take public transit to work than to drive, and whites are significantly less likely to ride the bus than to drive. A 10 percent increase in years of schooling raises the probability of riding rail by 1.1 percentage points in both samples; however, this implies quite different elasticities in each sample due to the baseline differences in the

[16] Marginal effects are computed by increasing the value of an explanatory variable for each worker in the sample and predicting the probability that the worker selects each mode. The average of these predicted probabilities is compared to the average of the predicted probabilities before changing the explanatory variable. For integer and dummy variables a one-unit change is evaluated; for continuous variables, a 10% change.

percent of commuters taking rail to work. Results for age, gender and household composition are not robust, which accords with much of the literature on mode choice.[17]

In examining the impacts of urban form and transit supply, two results stand out. The first is that the most robust effect of urban form, as measured by population centrality and jobs-housing balance, is to increase the probability of walking or bicycling to work. Population centrality increases the chances that a worker walks to work, with elasticities of 2.0 with and 1.0 without New York. In cities with greater jobs-housing imbalance workers are less likely to walk to work; however, the magnitude of this effect is low in both samples (elasticity = -0.3).

The second result is that increasing rail (bus) supply increases the modal share for rail (bus) in both samples, while reducing distance to the nearest transit stop has a significant impact on the probability of commuting by bus. The elasticity of the rail mode with respect to rail supply is, however, unbelievably large (over 7!) when New York is included in the sample, and is no doubt an artifact of the high modal share for rail in the New York area. When New Yorkers are excluded from the sample, the elasticity of the share of commuters taking rail with respect to rail supply (3.5) remains high, but is believable. The elasticity of bus ridership with respect to bus route miles is unity in full sample and 1.4 without New York. The elasticity of bus ridership with respect to distance to the nearest transit stop is -0.7 with and -1.0 without New York.

Although transit supply and population centrality have non-negligible percentage impacts on rail, bus and non-motorized modal shares, their impact on miles driven to work is small, due to the fact that a small percent of commuters take transit or walk to work. To summarize the quantitative impacts of sprawl and transit variables on the probability of driving to work, Table 6 presents probit models of the drive/no drive decision that are identical in specification to the

[17] Sarmiento (2000) in a review of the impact of gender and household composition on travel notes that the impact

models in Table 5. These models are used to calculate the marginal effect of a 10% change in each variable on the probability that a randomly chosen worker drives to work, which is expressed in percentage point terms.

Of all measures of urban form and transit supply, population centrality and distance to nearest transit stop have the largest impact on whether a worker drives to work. Their effects, while comparable in magnitude to the effects of income and education are, however, small in absolute terms, and are sensitive to the inclusion of New York in the sample. With New York, a 10 percent increase in population centrality lowers the probability of driving by 2.1 percentage points (elasticity = -0.26); without New York the same change reduces the probability of driving by 1 percentage point (elasticity = -0.11). If the average worker drives 6000 miles to work each year, this translates into a reduction of 60 miles annually. A 10% increase in distance to the nearest transit stop increases the chances of driving to work by approximately 1.6 percentage points in the entire sample (elasticity = 0.20) and by about 0.75 percentage points (elasticity = 0.08) when New York is removed. This is equal in magnitude to the elasticity of driving with respect to income (0.08 without New York).

The impacts of jobs-housing imbalance and rail and bus route miles on commute mode choice, while statistically significant, are generally smaller in magnitude than either population centrality or distance to nearest transit stop. The elasticity of the probability of driving with respect to jobs-housing imbalance is 0.11 in the full sample (p-value = .001) and 0.06 when NY is omitted (p-value = .02). The elasticity of driving with respect rail to supply is -0.063 in the full sample but only -0.029 in the sample without New York. The corresponding elasticities for bus route miles are -0.075 with New York and -0.046 without New York.

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of gender on mode choice varies considerably from one study to another.

These results are quite plausible in light of findings in the commute mode choice literature. Changes in distance to the nearest transit stop or in bus or rail route miles supplied should affect mode choice through their impact on walking times and waiting times for bus and rail. McFadden (1974) reports elasticities of the probability of driving to work with respect to transfer wait times of 0.07 for bus and 0.11 for rail, which are in line with our findings.

IV. Models of Automobile Ownership and Annual VMTs

Urban form and transit supply may influence household VMTs either by affecting the number of cars owned or the number of miles each car is driven. We therefore estimate a model to explain the number of cars owned and the demand for VMTs per vehicle (Train 1986; Walls, Harrington and Krupnick 2000; West 2000). The model is estimated in two parts. The first part is a multinomial logit model that explains whether the household owns zero, one, two, or three-or-more vehicles. We then study the determinants of annual VMTs per vehicle separately for households that own one, two, or three-or-more vehicles. Because unobservable factors that explain the number of vehicles owned may be correlated with the error terms in the VMT per vehicle equations, we use the selectivity correction approach developed by Dubin and McFadden (1984) to estimate the demand for VMT equations.

A. Specification of the Econometric Model

With some modification, the model presented in section II is compatible with the standard indirect utility model of vehicle choice and miles driven per vehicle. Suppose that the location choice/travel demand problem described in II.A is solved conditional on the household owning a vehicles, and that the direct utility function depends on the number of vehicles driven as well as the number of miles driven, $U(q,X,M,N,a)$. The household's budget constraint must be modified so that the fixed cost of owning a vehicles (F_a) is added to the right-hand-side of (3).

The household will select its travel demand, $\{I_i, I_w\}$, purchases of q and X and optimal location, τ, conditional on a. The resulting indirect utility function may be written:

(4) $\upsilon_a(\mathbb{p}', \mathbb{t}', \varphi, \phi, y\text{-}F_a, n(t), r(t), c(t), b(t))$

and the number of miles driven (conditional on a)

(5) $M = M(\mathbb{p}', \mathbb{t}', \varphi, \phi, y\text{-}F_a, n(t), r(t), c(t), b(t))$

where $y = (w\text{-}c_L)L$ is household income. The household will then select the number of vehicles to own by comparing υ_a for various a.

The empirical counterpart to this model is a discrete choice model of the number of vehicles owned and an equation for the average number of miles driven, conditional on owning a vehicles. Let the indirect utility household i receives from owning a vehicles be written as the sum of an unobservable component, u_{ia} and an observable component, V_{ia}, that includes household characteristics $\mathbb{Z}_i$ (which may affect utility), the price per mile of driving, φ, income net of the fixed costs of car ownership, $y_i\text{-}F_a$, and characteristics of the urbanized area in which the household lives, $\mathbb{S}_i$. The probability that the household owns a vehicles is given by (4')

(4') $P_a = P(V_{ia} + u_{ia} > V_{ib} + u_{ib}),\ all\ b \neq a$ where $V_{ia} = \mathbb{B}_a\mathbb{Z}_i + \mathit{\Gamma}_a\mathbb{S}_i + \beta_a\varphi_i + \gamma_a(y_i\text{-}F_a)$.

If the unobservable components $\{u_{ia}\}$ are assumed to be independently and identically distributed with a Type I Extreme Value distribution, the vehicle choice model becomes a multinomial logit model.

Conditional on a, the number of miles that a household drives, per vehicle, will depend on the same variables as enter the indirect utility function (4),

(5') $(M/a)_i = \mathbb{D}_a\mathbb{Z}_i + \mathit{\Omega}_a\mathbb{S}_i + \alpha_a\varphi_i + \delta_a(y_i\text{-}F_a) + \varepsilon_{ia.}$

Since the same unobservable variables that affect vehicle ownership are likely to affect miles driven, it is reasonable to assume that the error term in the average miles per vehicle equation, ε_i, will be correlated with u_{ia}. We handle this by adding the selectivity correction factor derived by Dubin and McFadden to equation (5′).

To estimate equations (4′) and (5′) we must measure the cost per mile driven and the fixed costs of vehicle ownership for each household. The fixed costs of vehicle ownership include the costs of interest and depreciation on the vehicle, as well as the cost of automobile insurance. The make, model and vintage of each vehicle the household owns is recorded in the NPTS. However, to avoid endogeneity problems (i.e. the chosen make, model may reflect the household's preferences for driving), we estimate the cost per mile and fixed costs of vehicle ownership for a typical household in household *i*'s income class. (Appendix C describes our calculation of the fixed costs of vehicle ownership and the price per mile traveled.) Price per mile is the price of gasoline in the household's MSA divided by the average fuel efficiency (miles per gallon) of vehicles owned by households in the household's income group. Household characteristics (***Z***) include the number of persons in the household classified by age and work status, the race of the household head and the number of years of schooling completed by the most educated person in the household. ***S*** includes the measures of urban form and transit supply from Table 2, as well as annual rainfall and annual snowfall.

These models are estimated using all households in the 1990 NPTS living in the 114 urbanized areas for which city-wide sprawl and transit measures have been computed and for whom complete data on VMTs are available. The subset of these households for which all other household variables are available is 8,297. As above, we estimate our models with and without households in the New York urbanized area.

B. The NPTS Household Sample

Table 7 presents the characteristics of households with complete VMT data in our full sample and in the sample excluding New York, according to number of vehicles owned. Several points are worth noting. With regard to vehicle ownership, households who own either 2 or 3 or more vehicles have higher incomes, more education, more workers and are more likely to be white than households who own either one or no vehicles. Secondly, average miles driven per vehicle are highest for two vehicle households (12,400 miles per year), and higher for one-vehicle (11,800) than for three or more vehicle (11,200) households. The difference in average miles driven per vehicle between one category and the next is, however, only about 600 miles per year. The accords with the fact that the substantial increases in vehicle miles traveled by U.S. households over the last two decades have occurred largely because of increases in the number of vehicles owned rather than in miles driven per vehicle. Finally, the difference in driving habits between the full sample and the sample including the New York urbanized area is small. In the sample including New York, approximately 14 percent of households own no passenger vehicles, 33 percent own one vehicle, 39 percent own two vehicles and 14 percent own three or more vehicles. The percentage of households owning no vehicles falls to 11% when New York is excluded and the percent owning 1, 2 or 3 or more increases slightly. Average VMTs per vehicle between the two samples are significantly different only for two-vehicle households (12453 miles without New York v. 12285 with New York).

C. Models of Vehicle Ownership

Table 8 presents the vehicle ownership models. The omitted category in each model is "owns no cars." In addition to reporting the multinomial logit coefficients and their standard errors, marginal effects, expressed as percentage point changes, are calculated for variables having a statistically significant impact on vehicle choice.[18]

[18] Marginal effects are calculated as in Table 5, by computing the impact of a unit change in race and in the number of family members and a 10% change in other variables on the probability that a household selects each alternative. These changes are averaged across households.

The impacts of household characteristics on vehicle ownership are largely as expected and agree with the literature. Household size and composition have a significant impact on the number of vehicles purchased, as found by Train (1980, 1986) and Mannering and Winston (1985). The probability of owning 3 or more vehicles is increased by 12 percentage points when a working adult male is added to a household, by 13 percentage points when a working adult female is added and by 21 percentage points when a young adult (aged 17-21) is added to the household. Adding a non-working adult increases the probability of owning 3 or more vehicles by almost 11 percentage points, while adding an elderly person to the household increases this probability by 3 percentage points. These results are robust to the inclusion or exclusion of New York from the sample. White households have a lower chance of owning no vehicles and higher chances of owning one, two or three or more vehicles than non-white households. When NY is excluded from the sample, black households have a higher chance of owning zero or one vehicle than non-black households. In general, adding an additional family member has a larger impact on the probability of owning 2 vehicles (or 3 or more vehicles) than does race.

Income and education have small but statistically significant impacts on car ownership. Increases in income (net of the fixed costs of car ownership) reduce the probability of a household owning one or no vehicles, but increase the probability that it owns two, or three or more vehicles. A 10% increase in income raises the probability of owning 2 vehicles by 0.8 percentage points (about 2.1%) and the probability of owning 3 or more vehicles by 0.5 percentage points (about 3.6%). A 10% increase in the years of schooling of the most educated household member increases the probability of owning 2 vehicles by 1.4 percentage points (3.6%) and the chances of owning 3 or more vehicles by 0.2 percentage points (1.4%). The fact that the vehicle ownership is inelastic with respect to income agrees with other U.S. studies based on household data (Mannering and Winston 1985, Train 1980).

Of our measures of urban form, only population centrality has a significant impact on the odds of car ownership. Households in less sprawled cities (cities with more centralized populations) are less likely to own one vehicle, two vehicles or three or more vehicles. A 10% increase in population centrality reduces the probability of owning 2 vehicles by about 1.5% and the probability of owning 3 or more vehicles by about 2% in both samples. Jobs-housing imbalance, by contrast, is never significantly different from zero at conventional levels, nor are city shape or road density.

Among measures of transit, lack of availability of public transit, as measured by instrumented distance from the nearest transit stop, significantly increases the probability of car ownership, for most vehicle categories. The impact is greatest on the probability of a household owning one vehicle: a 10% increase in instrumented distance to the nearest transit stop raises the probability of owning one vehicle by about 3%. Greater rail supply reduces the likelihood of vehicle purchase, conditional on a city having a rail system to begin with.[19]

D. Models of VMT per Vehicle and Effects on Total VMTs

Table 9 presents demand functions for VMTs per vehicle, estimated separately for one, two and three-or-more vehicle households. The selectivity correction term added to each equation is based on Table 8. Since the dependent variable is the logarithm of VMTs per vehicle, the coefficients in Table 9 represent the proportionate change in annual household VMTs corresponding to a one unit change in each variable (with the exception of the income variable), holding the household's vehicle stock constant. Table 10 summarizes the effects of changes in the variables in Tables 8 and 9 on the average annual vehicle miles driven by

[19] Note that equations (2) and (3) include a dummy variable (Rail Dummy) equal to one if a rail system is present and zero if it is not. Rail Supply may therefore be interpreted as the product of rail miles supplied and the Rail Dummy.

households in our sample; i.e., the sum of the average annual miles driven by households in each vehicle category weighted by the proportion of households in each category.[20]

The number of persons in a household has a significant impact on annual VMTs per vehicle; however, this effect is generally not as great as the impact of an additional person on VMTs that occurs through vehicle choice. Focusing on the results reported in Table 10 without New York, adding an adult male to a household raises average VMTs by about 6,000 miles annually, with most of this effect occurring through vehicle choice (5,000 miles) rather than miles per vehicle (1,000 miles). Adding a working adult female to the household or a young adult aged 17-21 increases driving by about 5,000 miles annually. In each case about 4,000 miles of this effect occurs through an increase in the number of vehicles owned rather than through an increase in miles driven per vehicle. In some cases (e.g., the elderly or a non-working adult) adding an additional person can reduce miles driven per vehicle, although not the number of vehicles owned. The former effect may occur if the individual either reduces the need for travel (a grandmother caring for children rather than the children attending a daycare center) or because the individual drives the car on trips that last a long time but involve short distances (e.g., shopping).

Previous studies (Mannering and Winston 1985, Train 1986) suggest that income has a small impact on vehicle usage, holding number of vehicles constant. Regardless of the number of vehicles owned, the elasticity of VMTs with respect to income is small, although the income elasticity of annual VMTs is about twice as high in one-vehicle households—0.30 without New York—as in two- or three-vehicle households (Table 9). As indicated in Table 10, the total impact of a 10% increase in income is to increase average annual VMTs by about 600 miles per

[20] Formally, let P1M1 + P2M2 + P3M3 be average household miles traveled before a variable is altered, where PI = proportion of households owning I vehicles and MI = annual average VMTs for households owning I vehicles, I=1,2,3. Let primes denote the value of each term after a variable is altered. In Table 10 we decompose the change in average annual VMTs as follows: $\Sigma PI'MI' - \Sigma PIMI = \Sigma(PI'-PI)MI + \Sigma PI'(MI'-MI)$.

year, a 3% increase. Approximately half of this effect occurs through an increase in miles driven per vehicle and half through an increase in the probability of owning more vehicles. A 10% increase in the years of schooling of the most educated household member increases average annual miles driven by about 7%, with two-thirds of this effect representing an increase in miles driven per vehicle (Table 10).

Our sprawl and transit measures have statistically significant impacts on miles driven per vehicle only in one-vehicle households (Table 9). An increase in road density increases annual miles driven by these households, as does an increase in jobs-housing imbalance. The more circular a city, the fewer the miles driven by one-vehicle households. In rail cities an increase in rail route miles reduces annual VMTs. The magnitude of these effects is, however, modest. As shown in Table 10, the effect of a 10% change in city shape, road density, rail supply (for rail cities) and jobs-housing imbalance is to change average annual miles driven by at most 0.7% for each variable.

Population centrality and distance to the nearest transit stop, which affect average VMTs through their effect on vehicle choice, have slightly larger, but still modest, effects. A one percent increase in population centrality reduces average annual miles driven by 1.5% when New York is removed from the sample. A 10% reduction in distance to nearest transit stop reduces annual average VMTs by about one percent.

V. Conclusions

The results presented above suggest that measures of urban sprawl (population centrality), jobs-housing balance and transit availability (rail supply and instrumented distance to the nearest transit stop) may have modest effects on the commute mode choices and annual VMTs of U.S. households. The results must, of course, be interpreted with caution—results for commute mode choice are based on only 26 cities with some form of rail transit. Although the results remain significant when New York City is removed from the sample, coefficient estimates vary depending on whether or not New York is included. Results for annual household VMTs are based on a broader sample and are less sensitive to the inclusion of New York City. They suggest that the elasticity of average annual VMTs with respect to individual measures of urban form are on the order of 0.2 in absolute value or less.

What implications do these results have for programs to control urban sprawl? Proponents of "smart growth" initiatives such as urban growth boundaries advocate non-price rather than price instruments as a means of controlling the externalities associated with sprawl. Are non-price instruments likely to be more or less effective than price instruments (e.g., gasoline taxes) in controlling VMTs? In a recent paper, Parry and Small (2001) report an average estimate of the price elasticity of VMTs in the United States of only -0.22. This is of the order of magnitude of the elasticity of VMTs with respect to population centrality. Parry and Small's elasticity figure is, however, smaller that most estimates reported in the literature. Puller and Greening (1999) for example, report a long-run elasticity of VMTs with respect to the price of gasoline of –0.7, considerably larger than the effects we find in this paper.

Programs to alter urban form are, however, likely to affect more than one measure of sprawl and transit availability simultaneously. To examine the impact of changing all of our measures of sprawl and transit availability we perform the following experiment: We predict the vehicle choices and VMTs per vehicle of all households in our sample, assuming that they live in a city with measures of urban form and transit availability (more specifically, all of the variables in Table 2) identical to those in Atlanta. We then repeat the experiment changing the vector of variables in Table 2 to (a) Boston and (b) New York. Table 11 summarizes the results of this experiment.

If the households in our sample were to live in a city with measures of urban form identical to those in Atlanta, Tables 8 and 9 predict that average annual VMTs per household would equal 17,697.[21] This number drops to 13,231 miles annually if the households in our sample move to a city with urban form and transit supply variables identical to Boston—a reduction in annual VMTs of 25%. This result is driven by differences in public transit supply, city shape and, especially, by differences in population centrality between the two cities. Atlanta is almost two standard deviations below the mean of all 114 cities in population centrality, whereas Boston is 0.66 standard deviations above the mean. Jobs housing imbalance is also lower in Boston than in Atlanta. When we move the households in our sample to New York the effect is even more striking—average annual VMTs per household fall to 10,145. This is the result of large differences in population centrality between Atlanta and New York (New York is almost two standard deviations above the mean for all U.S. cities), and of differences between the two cities in the supply of public transit, especially rail transit.

In terms of urban form and transit supply New York is clearly an outlier. The Atlanta-Boston comparison is, however, a more realistic one and indicates the potential for urban form and public transit to influence travel demand. In a political environment where it is difficult to raise gasoline or road taxes, programs that alter urban form and transit supply are potentially valuable tools available to policy-makers interested in reducing the social costs of driving.

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[21] Formally, we calculate $1/N \Sigma_i \Sigma_j P(i,j)M(i,j)$ where $P(i,j)$ is the predicted probability that household i purchases vehicle bundle j and $M(i,j)$ is the number of miles the household is predicted to travel conditional on owning bundle

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Table 1. Rankings of Cities Based on Various Sprawl Measures*

Urbanized Area	Population Density	Land Area	Jobs-Housing Imbalance	Population Centrality	City Shape	Supply of Rail Transit**	Supply of Bus Transit	Road Density
Los Angeles--Long Beach, CA	1	113	75	16	84	15	5	98
Miami, FL	2	84	42	63	114	9	2	101
New York, NY	3	114	95	5	46	1	4	92
Modesto, CA	4	1	5	82	88	-	29	108
Chicago, IL	5	112	63	58	94	2	6	77
San Jose, CA	6	81	96	43	96	12	13	96
New Orleans, LA	7	69	102	31	60	17	11	51
Fort Lauderdale, FL	8	79	33	106	68	-	15	95
Philadelphia, PA--NJ	9	109	52	17	13	6	12	60
Washington, DC--MD--VA--WV	10	105	105	36	17	4	16	71
Stockton--Lodi, CA	11	4	24	54	61	-	41	102
Fresno, CA	12	22	39	89	5	-	49	105
San Diego, CA	13	101	114	7	104	10	22	61

* 1 indicates the least sprawled in our sample

** Cities without any rail transit systems are indicated by -.

Table 2. Summary Statistics for City Level Variables in Various City Samples

	All Cities		Rail Cities		Non-Rail Cities	
Variable	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Number of Observations	114		26		88	
Annual Rainfall (inches)	42.01	16.27	41.24	17.86	42.23	15.87
Annual Snowfall (inches)	16.56	22.51	14.93	19.51	17.04	23.41
Gas Price in 1990 (cents)	115.53	5.30	115.20	6.58	115.62	4.90
Population Density (population per 1,000 km2)	0.94	0.34	1.26	0.44	0.84	0.23
Land Area (1,000 km2)	0.95	1.08	1.95	1.64	0.66	0.59
Density of Road Network (lane area per square mile)	0.04	0.01	0.04	0.01	0.04	0.02
Indicator for Rail Transit	0.23	0.42	1.00	0.00	0.00	0.00
Supply of Rail Transit (million miles per km2)	0.00	0.01	0.01	0.01	0.00	0.00
Supply of Non-Rail Transit (million miles per km2)	0.01	0.01	0.02	0.01	0.01	0.01
Population Centrality	0.15	0.02	0.16	0.02	0.15	0.02
Jobs-Housing Imbalance	0.33	0.10	0.37	0.08	0.31	0.10
Distance to nearest transit stop (blocks)	16.47	10.51	13.34	7.24	17.37	11.15
Instrumented Distance to Nearest Transit Stop (blocks)	20.06	2.67	17.34	3.74	20.86	1.53

Table 3. Correlation Matrix of Transit Supply and Sprawl Measures

	Land area	Population density	City shape	Jobs-Housing imbalance	Population centrality	Road density	Supply of bus transit	Supply of rail transit	Distance to nearest transit stop (Instrumented)
Land area	1.00								
Population density	0.49	1.00							
City shape	-0.04	-0.10	1.00						
Jobs-Housing imbalance	0.33	0.06	0.08	1.00					
Population centrality	0.09	0.16	-0.33	-0.34	1.00				
Road density	0.10	0.39	0.06	0.10	-0.15	1.00			
Supply of bus transit	0.40	0.73	-0.06	0.18	0.10	0.39	1.00		
Supply of rail transit	0.69	0.48	0.01	0.11	0.21	0.06	0.45	1.00	
Distance to nearest transit stop (Instrumented)	-0.67	-0.47	-0.07	-0.09	-0.13	-0.03	-0.50	-0.73	1.00

Table 4. Summary Statistics for Mode Choice Regression Sample

	Whole Sample				Sample Excluding New York City			
	Private Transport Users	Non-Rail Transit Users	Rail Transit Users	Non-Motorized Transport Users	Private Transport Users	Non-Rail Transit Users	Rail Transit Users	Non-Motorized Transport Users
	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)
Number of Observations (% of sample)	5156 (79.7%)	387 (6.0%)	510 (7.9%)	417 (6.4%)	3862 (86.7%)	221 (5.0%)	102 (2.3%)	271 (6.1%)
Age of Worker	38.88 (37.55)	36.99 (13.93)	35.24 (12.49)	37.25 (14.31)	37.73 (19.94)	36.44 (14.00)	35.78 (12.53)	36.63 (14.31)
Indicator for Female Worker	0.57 (0.50)	0.63 (0.48)	0.54 (0.50)	0.58 (0.49)	0.50 (0.50)	0.57 (0.50)	0.49 (0.50)	0.56 (0.50)
Number of Adults in Household	2.27 (0.92)	2.25 (1.14)	2.44 (1.32)	2.26 (1.09)	2.22 (0.85)	2.10 (0.99)	2.39 (0.87)	2.19 (0.89)
Number of Children in Household	0.96 (1.15)	0.90 (1.22)	0.74 (1.08)	0.91 (1.18)	0.96 (1.16)	0.82 (1.20)	0.70 (1.00)	0.89 (1.16)
Household Income / $ 5,000	10.70 (0.59)	10.44 (0.76)	10.73 (0.61)	10.55 (0.71)	10.64 (0.54)	10.24 (0.74)	10.57 (0.71)	10.43 (0.72)
Years of Education	13.80 (2.53)	13.15 (2.83)	14.24 (2.65)	13.53 (2.79)	13.77 (2.51)	13.03 (2.87)	15.14 (2.47)	13.49 (2.83)
White Household	0.81 (0.39)	0.50 (0.50)	0.57 (0.50)	0.77 (0.42)	0.81 (0.39)	0.48 (0.50)	0.72 (0.45)	0.79 (0.41)
Black Household	0.10 (0.30)	0.34 (0.47)	0.23 (0.42)	0.13 (0.34)	0.10 (0.30)	0.36 (0.48)	0.22 (0.41)	0.13 (0.34)
Distance to nearest transit stop (blocks)	12.10 (20.10)	2.56 (8.51)	2.45 (7.22)	5.50 (13.77)	14.54 (22.04)	3.10 (10.37)	4.10 (10.05)	7.57 (16.67)
Instrumented Distance to Nearest Transit Stop (blocks)	14.84 (5.64)	11.21 (6.32)	7.09 (4.63)	12.82 (6.45)	17.49 (3.42)	15.72 (3.79)	14.02 (3.08)	16.71 (3.77)

Table 5. Mode Choice Regressions

	Whole Sample						Excluding New York City					
	Non-Rail	ME[a]	Rail	ME[a]	NonMotor	ME[a]	Non-Rail	ME[a]	Rail	ME[a]	NonMotor	ME[a]
Age of Worker	-0.001 (0.29)	+0.0	-0.015 (5.71)***	-0.8	0.000 (0.01)	+0.1	-0.003 (0.34)		-0.009 (1.11)		-0.002 (0.26)	
Age Squared	-0.000 (0.70)	-0.0	0.000 (3.58)***	+0.0	-0.000 (0.80)	-0.0	-0.000 (0.15)		0.000 (0.96)		-0.000 (0.18)	
Indicator for Female Worker	0.629 (2.56)**	+2.9	0.319 (2.52)**	+1.2	0.114 (0.91)	+0.2	0.331 (1.43)		0.132 (0.45)		0.027 (0.19)	
Number of Adults in the Household	-0.005 (0.07)		0.068 (1.50)		0.027 (0.78)		-0.095 (0.65)	-0.5	0.281 (3.82)***	+0.7	0.043 (0.69)	+0.2
No. of Children Aged 5-21	0.028 (0.34)	+0.2	-0.046 (2.45)**	-0.3	0.010 (0.19)	+0.1	-0.122 (2.03)**	-0.5	-0.065 (0.71)	-0.1	-0.078 (1.25)	-0.4
Indicator for Female Workers with Children	-0.995 (2.32)**	-3.7	-1.494 (6.83)***	-7.6	-0.337 (0.82)	-0.7	-0.330 (0.93)		-0.496 (0.91)		0.305 (1.48)	
Log of Income	-0.624 (3.90)***	-0.3 **(-0.5)**	-0.315 (3.41)***	-0.1 **(-0.1)**	-0.443 (2.81)***	-0.2 **(-0.3)**	-0.807 (6.85)***	-0.3 **(-0.6)**	-0.887 (4.20)***	-0.2 **(-0.9)**	-0.678 (5.10)***	-0.3 **(-0.5)**
Years of Eduation	-0.013 (0.44)	-0.2 **(-0.3)**	0.122 (2.70)***	+1.1 **(+1.4)**	-0.001 (0.06)	-0.1 **(-0.2)**	-0.016 (0.31)	-0.2 **(-0.4)**	0.298 (5.88)***	+1.1 **(+4.8)**	0.000 (0.01)	-0.1 **(-0.2)**
White Household	-0.804 (4.93)***	-4.0	-0.877 (4.25)***	-5.1	0.036 (0.13)	+1.1	-0.977 (4.85)***	-5.2	0.125 (0.32)	+0.3	0.408 (1.28)	+3.4
Black Household	0.594 (2.98)***	+3.5	0.089 (0.78)	-0.0	0.099 (0.43)	+0.3	0.460 (1.43)	+1.9	0.840 (2.48)**	+2.1	0.399 (1.45)	+2.1
Annual Rainfall	0.002 (0.18)	+0.4 **(+0.7)**	-0.071 (2.49)**	-2.1 **(-2.7)**	-0.005 (0.94)	+0.1 **(+0.2)**	-0.009 (0.79)		-0.001 (0.03)		-0.006 (1.08)	
Annual Snowfall	-0.014 (0.16)		0.158 (1.11)		-0.033 (1.15)		-0.009 (0.11)		-0.013 (0.08)		0.008 (0.25)	
Gasoline cost of Driving per Mile	-0.008 (0.02)		0.077 (0.22)		0.233 (1.27)		-0.067 (0.23)		-0.782 (1.73)*		-0.065 (0.45)	
Road Density	17.206 (0.56)	+0.9 **(+1.5)**	-154.090 (2.42)**	-3.8 **(-4.8)**	39.723 (2.77)***	+1.6 **(+2.5)**	-9.774 (0.32)	-0.2 **(-0.4)**	-52.275 (1.25)	-0.5 **(-2.2)**	21.487 (2.56)**	+0.6 **(+1.0)**
Supply of Rail Transit	-7.967 (0.51)	-0.9 **(-1.5)**	181.105 (3.69)***	+5.9 **(+7.5)**	4.439 (0.50)	-0.5 **(-0.8)**	-13.856 (0.71)	-0.1 **(-0.2)**	216.018 (4.92)***	+0.8 **(+3.5)**	26.411 (2.04)**	+0.1 **(+0.2)**
Supply of Bus transit	50.389 (2.70)***	+0.6 **(+1.0)**	24.009 (0.68)	+0.2 **(+0.3)**	10.376 (1.10)	+0.1 **(+0.2)**	66.185 (3.01)***	+0.7 **(+1.4)**	-29.683 (0.97)	-0.2 **(-0.9)**	8.079 (0.76)	+0.0 **(+0.0)**
Distance to Nearest Transit Stop (Instrumented)	-0.079 (5.00)***	-0.4 **(-0.7)**	-0.088 (8.06)***	-0.3 **(-0.4)**	-0.068 (3.01)***	-0.4 **(-0.6)**	-0.073 (2.18)**	-0.5 **(-1.0)**	-0.018 (0.40)	-0.0 **(-0.0)**	-0.020 (0.60)	-0.2 **(-0.3)**
Population Centrality	11.912 (1.64)	+1.7 **(+2.8)**	-46.228 (2.53)**	-4.1 **(-5.2)**	8.522 (2.22)**	+1.3 **(+2.0)**	1.736 (0.21)	+0.0 **(+0.0)**	8.841 (0.50)	+0.3 **(+1.3)**	7.242 (1.93)*	+0.6 **(+1.0)**
Jobs-Housing Imbalance	-1.518 (1.18)	-0.2 **(-0.3)**	-2.929 (1.05)	-0.6 **(-0.8)**	-1.438 (2.72)***	-0.2 **(-0.3)**	-1.830 (1.25)	-0.3 **(-0.6)**	0.302 (0.10)	+0.0 **(+0.0)**	-1.059 (2.40)**	-0.2 **(-0.3)**
City Shape	0.685 (1.20)		-0.433 (0.52)		0.069 (0.28)		0.837 (1.49)		-1.236 (1.66)*		0.069 (0.29)	
Population Density	-0.813 (1.43)	-0.7 **(-1.2)**	0.149 (0.10)	+0.3 **(+0.4)**	-0.622 (2.03)**	-0.5 **(-0.8)**	-0.679 (1.20)		-0.169 (0.14)		-0.246 (1.01)	
Land Area	0.038 (0.39)		-0.353 (1.33)		-0.066 (1.21)		-0.009 (0.10)		0.020 (0.08)		-0.084 (1.79)*	
Constant	3.082 (0.63)		16.586 (2.67)***		0.254 (0.09)		8.678 (2.23)**		5.426 (1.10)		3.405 (2.38)**	
Observations	6470		6470		6470		4456		4456		4456	

Robust z statistics in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

[a]ME: percentage point marginal effect of a 10% increase (continuous variables) *or* a unit increase (discrete variables). For continous variables, the corresponding elasticity is reported in boldface in parentheses.

Table 6. Probit Model of the Driving Decision

	Whole Sample Drive	ME	Excluding NYC Drive	ME
Age of Worker	0.003 (1.48)	0.3	0.001 (0.46)	0.1
Age Squared	-0.000 (0.37)	0.0	0.000 (0.06)	0.0
Indicator for Female Worker	-0.191 (2.32)**	-0.3	-0.088 (1.19)	-0.1
Number of Adults in the Household	-0.020 (1.34)	-0.1	-0.019 (0.58)	-0.1
No. of Children Aged 5-21	-0.000 (0.01)	0.0	0.049 (2.06)**	0.1
Indicator for Female Workers with Children	0.517 (1.94)*	0.4	0.020 (0.13)	0.0
Log of Income	0.260 (3.44)***	0.6	0.405 (7.87)***	0.8
Years of Eduation	-0.020 (1.79)*	-0.7	-0.020 (1.07)	-0.6
White Household	0.330 (2.98)***	0.7	0.123 (1.29)	0.2
Black Household	-0.168 (2.55)**	-0.1	-0.264 (2.39)**	-0.1
Annual Rainfall	0.002 (0.93)	0.2	0.003 (1.23)	0.2
Annual Snowfall	0.014 (0.86)	0.1	-0.005 (0.27)	0.0
Gasoline cost of Driving per Mile	-0.068 (0.72)	-0.9	0.064 (0.91)	0.7
Road Density	-0.085 (2.24)**	-2.2	-0.028 (0.94)	-0.6
Supply of Rail Transit	-9.719 (2.39)**	-0.5	-19.835 (3.45)***	-0.3
Supply of Bus transit	-9.594 (1.89)*	-0.6	-11.111 (1.64)	-0.4
Distance to Nearest Transit Stop (Instrumented)	0.046 (6.14)***	1.6	0.022 (2.05)**	0.7
Population Centrality	-5.060 (2.17)**	-2.1	-3.113 (1.39)	-1.0
Jobs-Housing Imbalance	0.922 (3.54)***	0.9	0.684 (2.24)**	0.5
City Shape	-0.011 (0.09)	-0.1	-0.062 (0.49)	-0.1
Population Density	0.460 (2.75)***	1.9	0.247 (1.56)	0.7
Land Area	0.009 (0.33)	0.1	0.020 (0.80)	0.1
Constant	-1.328 (0.93)		-3.274 (3.70)***	
Observations	6470		4456	

Robust z statistics in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 7. Summary Statistics of Household Level Variables

	All Households				Sample without NY Households			
	No cars	1 car	2 cars	3+ cars	No cars	1 car	2 cars	3+ cars
Number of Elderly in Household	0.39	0.32	0.17	0.10	0.43	0.33	0.18	0.11
Number of Working Adult Males	0.21	0.37	0.72	0.85	0.16	0.35	0.71	0.84
Number of Working Adult Females	0.26	0.40	0.56	0.71	0.22	0.39	0.57	0.70
Number of Non-Working Adults	0.34	0.24	0.31	0.35	0.35	0.23	0.30	0.35
Number of Children Aged 17-21	0.16	0.09	0.10	0.36	0.15	0.09	0.10	0.36
Number of Children Aged 0-16	0.46	0.41	0.79	0.59	0.50	0.40	0.76	0.59
Log of Adjusted Income	10.00	10.25	10.63	10.72	9.74	10.17	10.58	10.70
Years of Schooling of Most Educated Member	12.20	13.76	14.70	14.83	11.84	13.67	14.64	14.78
White Household	0.55	0.82	0.87	0.87	0.59	0.83	0.87	0.87
Black Household	0.32	0.12	0.07	0.06	0.33	0.11	0.07	0.06
Average VMTs per Vehicle	0	11720	12285	11206	0	11839	12453	11247
Percentage of Total Households	0.14	0.33	0.39	0.14	0.11	0.34	0.41	0.15
Number of Observations	1144	2736	3220	1197	704	2270	2797	1037

Table 8. Multinomial Logit Models of Vehicle Choice

	All observations						Excluding New York City					
	1-car	ME	2-car	ME	3+-car	ME	1-car	ME	2-car	ME	3+-car	ME
Elderly	-0.023 (0.33)	-7.5	0.525 (4.79)***	+6.2	0.631 (4.94)***	+3.0	-0.048 (0.51)	-9.1	0.599 (4.40)***	+7.0	0.729 (4.97)***	+3.6
Working Adult Males	0.689 (7.95)***	-15.3	1.975 (12.84)***	+11.0	2.532 (15.51)***	+12.4	0.760 (5.16)***	-16.8	2.138 (11.86)***	+11.0	2.695 (13.76)***	+12.4
Working Adult Females	0.505 (3.86)***	-11.9	1.413 (6.13)***	+5.4	2.094 (9.05)***	+13.0	0.672 (4.11)***	-13.9	1.718 (9.44)***	+6.4	2.386 (11.54)***	+13.2
Non-Working Adults	-0.067 (0.70)	-12.7	0.800 (8.36)***	+5.1	1.364 (11.26)***	+10.5	-0.144 (1.30)	-14.1	0.805 (5.66)***	+5.3	1.378 (8.11)***	+10.9
Children Aged 17-21	-0.368 (3.00)***	-12.9	0.183 (1.13)	-6.5	1.417 (6.56)***	+19.7	-0.229 (1.78)*	-13.2	0.362 (2.05)**	-7.5	1.671 (8.95)***	+21.9
Children Aged 0-16	0.019 (0.29)	-2.2	0.236 (2.79)***	+4.6	-0.012 (0.13)	-1.7	-0.067 (1.37)	-2.4	0.128 (2.25)**	+4.3	-0.122 (1.73)*	-2.0
Log of Adjusted Income	0.207 (1.96)*	-0.9	0.930 (6.17)***	+0.8	1.197 (4.27)***	+0.5	0.330 (4.85)***	-1.0	1.107 (11.04)***	+0.7	1.526 (11.23)***	+0.7
Years of Schooling of Most Educated Member	0.165 (8.25)***	+0.3	0.207 (9.97)***	+1.4	0.196 (7.95)***	+0.2	0.183 (8.33)***	+0.2	0.221 (8.14)***	+1.4	0.202 (5.93)***	-0.0
White Household	1.139 (5.84)***	+4.2	1.328 (4.12)***	+4.8	1.557 (3.92)***	+3.7	0.796 (4.53)***	+3.2	0.830 (3.81)***	+1.5	0.957 (4.06)***	+1.8
Black Household	-0.132 (0.52)		-0.432 (1.46)		-0.526 (1.35)		-0.556 (3.02)***	+2.0	-0.865 (3.38)***	-4.2	-1.057 (3.40)***	-3.2
Annual Rainfall	0.005 (0.96)		0.000 (0.07)		-0.004 (0.60)		0.008 (1.53)		0.003 (0.57)		-0.002 (0.30)	
Annual Snowfall	-0.033 (1.26)		-0.001 (0.02)		-0.016 (0.34)		-0.035 (1.40)		-0.005 (0.15)		-0.022 (0.49)	
Gasoline cost of Driving per Mile	-0.018 (0.08)		-0.523 (1.55)		-0.561 (1.56)		0.127 (0.87)		-0.278 (1.40)		-0.286 (1.19)	
Road Density	-1.860 (0.25)		-2.937 (0.41)		-5.332 (0.63)		-2.540 (0.33)		-3.532 (0.49)		-6.257 (0.74)	
Presence of Rail Transit	-0.122 (0.98)		-0.154 (1.04)		-0.129 (0.62)		-0.208 (2.06)**		-0.233 (1.87)*		-0.218 (1.21)	
Supply of Rail Transit	2.583 (0.28)		0.517 (0.05)		-1.625 (0.11)		8.452 (0.62)		-3.722 (0.26)		-9.466 (0.43)	
Supply of Bus Transit	-5.280 (0.61)	+0.2	-19.873 (1.69)*	-0.4	-9.124 (0.58)	+0.1	-6.719 (0.82)	+0.2	-20.489 (1.83)*	-0.4	-9.564 (0.61)	+0.1
Population Centrality	-9.825 (3.71)***	-0.6	-10.947 (3.00)***	-0.6	-11.782 (2.83)***	-0.3	-9.233 (3.39)***	-0.2	-10.987 (3.42)***	-0.5	-12.213 (2.99)***	-0.4
City Shape	-0.346 (1.10)		-0.536 (1.38)		-0.639 (1.42)		-0.260 (0.94)		-0.472 (1.43)		-0.583 (1.45)	
Jobs-Housing Imbalance	-0.239 (0.39)		0.567 (0.80)		0.435 (0.42)		-0.058 (0.10)		0.742 (1.17)		0.650 (0.64)	
Land Area	-0.036 (0.54)	+0.3	-0.148 (1.93)*	-0.5	-0.115 (1.17)	-0.0	-0.002 (0.04)	+0.2	-0.110 (1.73)*	-0.3	-0.077 (0.87)	-0.0
Population Density	0.539 (1.93)*	+0.3	0.674 (2.33)**	+0.6	0.459 (1.14)	-0.2	0.584 (2.13)**	+0.2	0.700 (2.52)**	+0.5	0.474 (1.20)	-0.2
Distance to Nearest Transit Stop (Instrumented)	0.099 (3.04)***	+1.0	0.087 (2.43)**	-0.0	0.096 (1.77)*	+0.2	0.117 (3.24)***	+1.4	0.097 (2.96)***	-0.1	0.103 (1.78)*	+0.1
Constant	-4.433 (1.72)*		-10.760 (3.26)***		-15.099 (3.19)***		-7.007 (4.99)***		-14.089 (7.93)***		-19.860 (7.68)***	

Robust z statistics in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 9. VMTs per Vehicle Models

Dependent Variable: Average ln(VMT) per car

	All observations			Excluding NYC		
	1-car	2-car	3+-car	1-car	2-car	3+-car
Elderly	-0.186 (2.70)***	-0.191 (5.38)***	-0.021 (0.46)	-0.193 (2.09)**	-0.214 (6.31)***	-0.000 (0.00)
Working Adult Males	0.479 (5.87)***	0.071 (1.78)*	0.079 (1.93)*	0.541 (4.05)***	0.056 (1.36)	0.043 (0.95)
Working Adult Females	0.244 (3.26)***	-0.004 (0.09)	0.045 (0.95)	0.259 (2.13)**	-0.031 (0.64)	0.008 (0.14)
Non-Working Adults	0.020 (0.26)	-0.054 (1.34)	0.022 (0.34)	0.088 (0.72)	-0.077 (1.93)*	-0.033 (0.55)
Children Aged 17-21	0.338 (3.81)***	0.041 (0.72)	0.164 (2.34)**	0.390 (3.07)***	0.071 (1.19)	0.116 (1.54)
Children Aged 0-16	0.042 (1.29)	-0.011 (0.60)	-0.039 (1.72)*	0.040 (0.99)	-0.021 (1.26)	-0.035 (1.33)
Log of Adjusted Income	0.227 (3.46)***	0.131 (3.90)***	0.127 (2.80)***	0.298 (4.66)***	0.127 (3.22)***	0.114 (1.81)*
Years of Schooling of Most Educated Member	0.043 (3.43)***	0.028 (4.93)***	0.033 (2.56)**	0.032 (2.88)***	0.028 (4.29)***	0.035 (2.50)**
White Household	0.069 (0.64)	0.080 (1.37)	-0.016 (0.19)	-0.017 (0.16)	0.074 (1.10)	-0.042 (0.44)
Black Household	-0.091 (0.65)	-0.068 (0.69)	0.024 (0.20)	-0.194 (1.43)	-0.095 (0.84)	0.023 (0.16)
Annual Rainfall	0.002 (0.81)	0.000 (0.25)	0.002 (0.83)	0.002 (0.64)	0.001 (0.53)	0.003 (1.08)
Annual Snowfall	-0.010 (0.42)	-0.009 (1.57)	0.010 (0.58)	-0.015 (0.64)	-0.008 (1.25)	0.010 (0.57)
Gasoline cost of Driving per Mile	0.003 (0.03)	0.010 (0.16)	-0.086 (0.84)	0.058 (0.65)	0.011 (0.16)	-0.058 (0.53)
Road Density	7.611 (2.60)**	1.065 (0.70)	0.809 (0.30)	7.304 (2.47)**	1.124 (0.73)	1.070 (0.39)
Presence of Rail Transit	-0.056 (0.72)	0.047 (1.26)	-0.041 (0.54)	-0.050 (0.68)	0.035 (0.97)	-0.055 (0.73)
Supply of Rail Transit	-8.450 (1.76)*	-3.994 (1.48)	-3.098 (0.67)	-16.002 (2.25)**	0.407 (0.07)	-0.464 (0.05)
Supply of Bus Transit	-6.980 (1.27)	-3.528 (0.80)	-6.397 (0.84)	-6.107 (1.08)	-3.361 (0.77)	-6.909 (0.88)
Population Centrality	2.002 (1.35)	-0.058 (0.08)	-0.299 (0.22)	1.456 (0.96)	0.187 (0.23)	-0.130 (0.09)
City Shape	-0.298 (2.37)**	0.094 (0.80)	-0.247 (1.33)	-0.318 (2.55)**	0.104 (0.89)	-0.239 (1.33)
Jobs-Housing Imbalance	0.870 (1.85)*	0.347 (1.58)	0.204 (0.64)	0.842 (1.85)*	0.358 (1.65)	0.219 (0.68)
Population Density	-0.055 (0.42)	-0.016 (0.22)	0.104 (0.73)	-0.069 (0.54)	-0.019 (0.25)	0.112 (0.79)
Land Area	-0.016 (0.45)	0.010 (0.54)	0.002 (0.09)	-0.016 (0.45)	0.016 (0.90)	0.008 (0.31)
Distance to Nearest Transit Stop (Instrumented)	-0.023 (1.21)	-0.001 (0.07)	-0.006 (0.29)	-0.030 (1.47)	0.005 (0.34)	-0.003 (0.14)
Selectivity Correction Factor	0.090 (3.34)***	0.004 (0.20)	-0.022 (1.04)	0.096 (2.24)**	0.016 (0.82)	-0.003 (0.14)
Constant	5.892 (4.80)***	7.147 (11.04)***	7.574 (6.97)***	5.374 (4.37)***	7.101 (10.75)***	7.617 (6.24)***
R-squared	0.10	0.07	0.04	0.12	0.08	0.04

Robust t statistics in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 10. Marginal Effects on Annual Total VMTs

Increase of..	Variable	Whole Sample			Excluding NYC		
		Total impact	Vehicle Choice*	VMTs**	Total impact	Vehicle Choice*	VMTs**
1	Working Adult Male	7,450 miles (39.7%)	5,563 miles	1,887 miles	6,070 miles (31.6%)	4,947 miles	1,124 miles
1	Working Adult Female	5,160 miles (27.5%)	4,900 miles	260 miles	4,779 miles (24.9%)	4,523 miles	256 miles
1	Working Child	8,926 miles (47.6%)	7,955 miles	971 miles	8,461 miles (44.1%)	7,594 miles	867 miles
10%	Education	1,358 miles (7.2%)	452 miles	906 miles	1,239 miles (6.5%)	371 miles	868 miles
10%	Income	568 miles (3.0%)	277 miles	291 miles	588 miles (3.1%)	292 miles	296 miles
10%	Population Centrality	-340 miles (-1.8%)	-340 miles	0 miles	-281 miles (-1.5%)	-281 miles	0 miles
10%	City Shape	-78 miles (-0.4%)	0 miles	-78 miles	-84 miles (-0.4%)	0 miles	-84 miles
10%	Road Density	135 miles (0.7%)	0 miles	135 miles	127 miles (0.7%)	0 miles	127 miles
10%	Supply of Bus Transit	n.s.			-1 mile (0.0%)	-1 miles	0 miles
10%	Supply of Rail Transit	-70 miles (-0.4%)	0 miles	-70 miles	-40 miles (-0.2%)	0 miles	-40 miles
10%	Jobs-Housing Imbalance	114 miles (0.6%)	0 miles	114 miles	107 miles (0.6%)	0 miles	107 miles
10%	Instrumented Distance to Nearest Transit Stop	+167 miles (0.9%)	168 miles	0 miles	+151 miles (0.8%)	151 miles	0 miles

* Calculated on the basis of models in Table 8

** Calculated on the basis of models in Table 9

Table 11. Predicted VMTs if our entire sample lived in Atlanta, Boston or New York City

Urbanized Area	Atlanta, GA	Boston, MA	New York, NY
Lane Density (area of roads per square mile of land)	0.04	0.04	0.05
Land Area (km2)	2,944	2,308	7,683
Population	2,157,806	2,775,370	16,044,012
Density (people per square kilometer)	733	1,202	2,088
Rail Transit Supply (10000 miles per km2)	0.7	1.8	5.7
Non-Rail Transit Supply (10000 miles per km2)	1	1.3	3
Jobs-Housing Imbalance (standardized)	0.47	-0.63	0.04
Population Centrality (standardized)	-1.83	0.66	1.8
City Shape	0.264	0.816	0.727
Predicted Averege VMTs per Household	17,697	13,231	10,145

Appendix A
Data Appendix

<u>VMT, Mode Choice and Individual/Household Characteristics:</u>

These data come from the various datasets of the *1990 Nationwide Personal Transportation Survey (NPTS)*. The datasets include separate files for vehicles, individuals, and households. We use information from the vehicle dataset to re-construct the annual VMTs per household, as well as the number of vehicle owned. The household annual VMTs are obtained by summing the per vehicle VMTs for vehicles types 1 through 4 which include: automobiles, including station wagons, passenger and cargo vans as well as pickup trucks. If a vehicle has been owned for less than a year, annualized VMTs for the vehicle are calculated using the following formula: the reported vehicle miles are divided by the number of months the car has been owned and then multiplied by 12 to obtain an annual figure. VMTs per car are capped at 115,000 miles. In total, 4 households are affected by this cap. In the original NPTS household dataset households who report having cars, but do not report VMTs for any of their cars are assigned zero household VMTs. We, on the other hand, classify these households as having missing VMT information, hence these households are not part of our sample. We also classify household VMTs as missing when there is incomplete information for some of the cars owned by the household. Of the 10,406 households in the urbanized areas of interest, we lost 2,606 households due to incomplete VMT data.

The household composition variables—number of elderly, number of working adult males, number of working adult females, number of children (ages 17 to 21), number of children (ages 0 to 16)—and the education of the most educated person in the household are constructed from the individual level file. Also, the variables used in the mode choice analyses come from the individual dataset.

The race variables and the distance to the nearest transit stop were obtained from the household level dataset. Household income is also obtained from this dataset. If, however, the income was missing for a household, it was predicted using other household level variables. There are 1,801 households in the vehicle choice/VMT analyses for which predicted income is used.

<u>Population Centrality Measure:</u>

The measure is calculated from the *1990 Decennial Census of Population and Housing Characteristics* as reported in the 1990 Census CD (Geolytics Inc.). The census tracts within each urban area are sorted in ascending distance from the CBD. We use the centroid of each tract to calculate distance from the CBD. The cumulative population is then plotted against the cumulative distance from the CBD expressed as a percent of the city radius. We calculate the area between this curve and the 45 degree line, which represents uniform distribution of population within the urban area. (See Figure 1.) Lower values imply a more uniform population distribution and more sprawl.

City Shape Measure:

The measure is calculate using the equal area elliptical projection feature of ArcGIS, using the urban area boundaries in the 1990 Census CD (Geolytics Inc.). The features calculates the minor and major axes of an ellipse that has the same area and general shape as the irregularly shaped urban area. We calculate the ratio between the minor and the major axes. In a perfectly circular city this ratio will be 1. The narrower and longer the actual city shape is, the lower the ratio.

Jobs-Housing Imbalance Measure:

The jobs-housing imbalance measure is calculated using the employment data at the zip code level from the *1990 Zip Code Business Patterns.* These data do not include self-employed persons, domestic service workers, railroad employees, agriculture production workers, and most government employees. The total number of employees is obtained by multiplying the various number of employees size categories by the mid-point of the range. The population figures at the zip code come from the *1990 Decennial Census of Population and Housing Characteristics*. Only zip codes that were in the urbanized part of an MSA are used. The zip codes are ordered from the zip code having the smallest number of jobs to the one having the largest and then the cumulative percent of jobs is plotted against the cumulative percent of population to obtain a Lorenz curve. The 45-degree line represents an even distribution of jobs v. population. Our *imbalance* measure (Massey and Denton's Gini coefficient) is the area between the Lorenz curve and the 45-degree line, expressed as a proportion of the area under the 45-degree line. Larger values of this measure imply a less even distribution of jobs versus housing.

Urban Population and Urban Land Area:

These figures come from the U.S. Census Bureau's *1990 Decennial Census of Population and Housing Characteristics*.

Rail and Non-Rail Transit Data:

These data come from the *1994 National Transit Database*. Transit agencies are grouped by urbanized areas and transit data provided by these agencies are summed to obtain the transit figures. The only exception is the New Jersey Transit Agency which is divided between Philadelphia, Trenton and New York, with shares of 10, 20 and 70 percent, respectively.

Road Density:

The data are calculated from the *1990 Highway Statistics*. First, the number of lane miles per urbanized area is calculated and multiplied by an estimated lane width (thirteen feet). The resulting area of road is divided by the corresponding land area in the *1990 Highway Statistics*.

Weather Data:

The weather data come from the National Oceanic and Atmospheric Administration's TD3220 files for 1990. The data are from a weather station in or near the urbanized area.

Cost of Car Ownership Data:

Gas price data are from Walls, Harrington and Krupnick (2000), whose gasoline prices for self-serve, unleaded gasoline come from two sources. The majority of the data come from the American Chamber of Commerce Research Association (ACCRA) for the Metropolitan Statistical Areas associated with our urban areas. When there are gaps in the ACCRA data, the price of gas is obtained from the Bureau of Labor Statistics for the Consolidated Metropolitan Statistical Area (CMSA) associated with the urban area. The insurance data, which are state-wide average, come from the Insurance Information Institute (personal communication). The car price and fuel economy data come from the Kelley Blue Book. (See Appendix C for a complete description of the car ownership calculations.)

Instrumented Distance to Local Transit:

This was calculated as follows. For each household in our sample we identified all the census tracts in their city that they could afford to live in based on their income. To correct for the fact that some households reside in tracts where the average income is higher than their own income, an "effective" income was determined for each household. The effective income was based on estimates obtained from the *1995 Nationwide Personal Transportation Survey* where both the household's income and the mean income of the household's census block group are reported. For the urban households in the 1995 NPTS, the maximum of the household's income and the mean income of the block group in which they resided was determined. This larger of these two incomes became the effective income. The effective income in the 1995 sample was regressed on the household's own income, household composition variables as well as educational attainment and race. The coefficient estimates from this regression were used to calculate the effective income for the 1990 NPTS sample. If the effective income generated by this method was more than the household's reported income, the effective income was used to determine the census tracts that the household could afford to live in; otherwise, the household's reported income was used for the calculation. Once the affordable tracts in the household's urbanized area were identified, we averaged across all tracts the proportion of the population taking public transit to work. The actual distance from the nearest transit stop was regressed against the average percent of workers using public transit for commuting to obtain an instrument for local availability of public transit. The data on percentage of tract population using various means of transportation to work were obtained from the *1990 Decennial Census of Population and Housing Characteristics*.

Data Sources:

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Office of Highway Policy Information. *Highway Statistics 1990*, Federal Highway Administration, Tables HM-71 and HM-72.

U.S. Bureau of Census. *1990 Decennial Census of Population and Housing Characteristics.*

U.S. Department of Transportation. *1990 Nationwide Personal Transportation Survey.*

Appendix B

Urbanized Area	Number Reporting Commute Mode Choice in Rail Cities	% taking Private Transport to Work	% taking Non-Rail Public Transit to Work	% taking Rail Public Transit to Work	% taking Non-Motorized Modes to Work	Rail Transit Supply (10000 miles per km2)	Non-Rail Transit Supply (10000 miles per km2)	Density of Road Network (area of roads*100 per square mile of land)	Land Area (km2)	Population (1000's)	Population Density (people per km2)	Jobs-Housing Imbalance (Standardized)	Population Centrality (standardized)	City Shape	Average VMTs per Household	Number of Housholds with in Sample
Akron, OH	.	.	.	.	.	0.0	0.8	5.8	666	528	793	-1.66	-1.05	0.70	20,913	31
Albany--Schenectady--Troy, NY	.	.	.	.	.	0.0	1.3	3.3	540	509	942	-0.69	0.87	0.62	13,764	28
Albuquerque, NM	.	.	.	.	.	0.0	0.8	5.1	585	497	850	0.32	-0.47	0.73	24,113	23
Allentown--Bethlehem--Easton, PA	.	.	.	.	.	0.0	0.8	5.1	368	410	1,115	-2.07	2.02	0.37	12,746	27
Atlanta, GA	202	88.1	4.0	4.0	4.0	0.7	1.0	3.9	2,944	2,158	733	1.19	-1.88	0.26	23,017	126
Augusta--Aiken, GA--SC	.	.	.	.	.	0.0	0.2	3.3	489	287	586	-0.58	-0.61	0.45	18,900	5
Austin--San Marcos, TX	.	.	.	.	.	0.0	1.9	10.1	708	562	794	0.03	0.44	0.71	17,613	40
Bakersfield, CA	.	.	.	.	.	0.0	1.0	3.8	255	303	1,189	-0.41	-1.07	0.63	21,048	13
Baltimore, MD	161	82.0	9.3	1.2	7.5	0.8	1.4	3.8	1,535	1,890	1,232	-0.69	1.18	0.75	18,315	103
Baton Rouge, LA	.	.	.	.	.	0.0	0.3	3.8	480	366	762	0.53	0.01	0.60	37,950	10
Birmingham, AL	.	.	.	.	.	0.0	0.3	3.9	1,033	622	602	1.23	0.18	0.62	18,058	24
Boston, MA--NH	183	76.0	3.3	8.7	12.0	1.8	1.3	4.3	2,308	2,775	1,202	-0.47	0.80	0.82	19,518	112
Bridgeport, CT	.	.	.	.	.	0.0	0.6	4.8	416	414	995	-2.11	1.77	0.62	19,050	198
Buffalo--Niagara Falls, NY	49	93.9	2.0	0.0	4.1	0.1	1.1	4.2	739	954	1,291	-1.03	-0.38	0.54	18,233	43
Canton--Massillon, OH	.	.	.	.	.	0.0	0.4	7.1	282	245	866	-1.05	-0.07	0.67	20,528	26
Charleston--North Charleston, SC	.	.	.	.	.	0.0	0.2	2.3	650	394	606	0.19	0.61	0.44	18,463	14
Charlotte--Gastonia--Rock Hill, NC--SC	.	.	.	.	.	0.0	0.9	4.1	626	456	728	0.69	-1.42	0.79	20,242	43
Chattanooga, TN--GA	43	93.0	0.0	0.0	7.0	0.0	0.3	3.2	665	297	446	-0.05	-1.18	0.69	13,795	28
Chicago, IL	565	82.3	5.0	6.4	6.4	1.9	2.7	4.7	4,104	6,792	1,655	0.24	-0.09	0.48	17,059	351
Cincinnati, OH--KY--IN	.	.	.	.	.	0.0	1.1	3.3	1,325	1,213	915	0.52	-0.28	0.71	20,457	92
Cleveland, OH	123	86.2	8.1	1.6	4.1	0.2	1.4	4.3	1,647	1,677	1,019	-0.06	-0.49	0.56	16,725	79
Columbia, SC	.	.	.	.	.	0.0	0.4	3.7	515	328	638	0.96	-0.80	0.71	15,826	21
Columbus, GA--AL	.	.	.	.	.	0.0	0.4	3.4	343	221	643	1.43	-1.58	0.83	54,143	7
Columbus, OH	.	.	.	.	.	0.0	1.0	5.1	893	945	1,058	0.31	-0.49	0.80	18,072	64
Corpus Christi, TX	.	.	.	.	.	0.0	0.9	6.3	403	270	670	-0.45	0.06	0.50	20,810	10
Dallas, TX	.	.	.	.	.	0.0	1.2	6.4	3,737	3,198	856	1.13	0.14	0.52	21,883	168
Davenport--Moline--Rock Island, IA--IL	.	.	.	.	.	0.0	0.7	3.8	378	264	698	-1.83	0.31	0.69	15,176	19
Daytona Beach, FL	.	.	.	.	.	0.0	0.6	4.3	331	221	669	-0.98	1.53	0.24	20,229	14
Dayton--Springfield, OH	.	.	.	.	.	0.0	1.3	5.0	708	613	866	0.01	-0.14	0.78	19,226	47
Denver, CO	156	88.5	4.5	0.0	7.1	0.0	2.3	6.5	1,188	1,518	1,277	1.14	-1.04	0.82	19,941	106

Appendix B

Urbanized Area	Number Reporting Commute Mode Choice in Rail Cities	% taking Private Transport to Work	% taking Non-Rail Public Transit to Work	% taking Rail Public Transit to Work	% taking Non-Motorized Modes to Work	Rail Transit Supply (10000 miles per km2)	Non-Rail Transit Supply (10000 miles per km2)	Density of Road Network (area of roads*100 per square mile of land)	Land Area (km2)	Population (1000's)	Population Density (people per km2)	Jobs-Housing Imbalance (Standardized)	Population Centrality (standardized)	City Shape	Average VMTs per Household	Number of Housholds with in Sample
Des Moines, IA	.	.	.	.	.	0.0	0.4	5.4	414	294	710	0.44	-0.64	0.91	24,251	16
Detroit, MI	307	94.5	1.0	0.0	4.6	0.0	1.0	4.8	2,899	3,698	1,275	0.86	-0.74	0.80	21,836	214
El Paso, TX	.	.	.	.	.	0.0	1.3	6.7	571	571	1,000	0.85	-0.86	0.45	17,060	16
Fayetteville, NC	.	.	.	.	.	0.0	0.2	3.5	355	242	681	1.07	-1.63	0.64	21,018	8
Flint, MI	.	.	.	.	.	0.0	1.0	3.6	424	326	768	-0.73	0.00	0.87	19,343	13
Fort Lauderdale, FL	.	.	.	.	.	0.0	2.0	5.4	847	1,238	1,461	-0.67	-1.28	0.62	17,727	71
Fort Myers--Cape Coral, FL	.	.	.	.	.	0.0	0.6	2.9	322	221	686	1.44	-0.84	0.62	16,975	20
Fort Wayne, IN	.	.	.	.	.	0.0	0.4	5.3	270	248	922	0.62	-0.62	0.69	12,454	18
Fresno, CA	.	.	.	.	.	0.0	1.0	6.4	344	453	1,319	-0.34	-0.79	0.93	20,521	27
Grand Rapids--Muskegon--Holland, MI	.	.	.	.	.	0.0	0.7	3.6	578	436	755	0.03	0.18	0.69	21,859	33
Greenville--Spartanburg--Anderson, SC	.	.	.	.	.	0.0	0.5	2.8	384	248	647	0.21	-0.35	0.93	29,649	13
Harrisburg--Lebanon--Carlisle, PA	.	.	.	.	.	0.0	0.3	3.9	388	293	755	-1.20	0.22	0.52	23,556	20
Hartford, CT	504	90.7	4.2	0.0	5.2	0.1	1.3	3.3	625	546	874	-1.22	0.97	0.56	19,254	319
Houston, TX	.	.	.	.	.	0.0	1.4	5.2	3,049	2,902	952	1.18	-1.14	0.80	24,908	141
Huntsville, AL	.	.	.	.	.	0.0	0.3	2.0	343	180	526	0.57	0.23	0.81	17,813	5
Indianapolis, IN	.	.	.	.	.	0.0	0.5	4.4	1,214	915	753	-0.09	-0.79	0.76	19,604	730
Jackson, MS	.	.	.	.	.	0.0	0.2	3.5	562	289	515	0.30	-0.51	0.77	22,383	8
Jacksonville, FL	56	98.2	0.0	0.0	1.8	0.0	0.6	3.2	1,315	738	562	0.39	0.02	0.76	19,698	37
Knoxville, TN	.	.	.	.	.	0.0	0.3	2.8	567	304	537	-0.09	0.54	0.67	17,624	17
Lansing--East Lansing, MI	.	.	.	.	.	0.0	1.2	3.6	256	265	1,037	-1.36	-0.76	0.63	14,313	14
Las Vegas, NV--AZ	.	.	.	.	.	0.0	1.7	10.6	598	697	1,165	2.00	-0.56	0.73	20,395	25
Lawrence, MA--NH	.	.	.	.	.	0.0	0.5	3.6	286	237	830	-0.33	1.34	0.72	29,794	13
Lexington, KY	.	.	.	.	.	0.0	0.5	2.9	254	221	868	-0.93	0.25	0.93	23,251	14
Little Rock-North Little Rock, AR	.	.	.	.	.	0.0	0.4	7.4	516	305	592	0.50	-0.73	0.49	17,910	24
Lorain--Elyria, OH	.	.	.	.	.	0.0	0.1	3.2	381	224	589	-1.12	0.18	0.56	16,984	8
Los Angeles--Long Beach, CA	548	88.0	6.4	0.0	5.7	0.1	2.8	5.8	5,091	11,403	2,240	0.46	0.99	0.55	19,864	358
Louisville, KY--IN	.	.	.	.	.	0.0	1.4	3.6	732	755	1,032	0.17	-1.05	0.87	22,558	43
Lowell, MA--NH	.	.	.	.	.	0.0	0.5	3.6	174	182	1,046	-2.22	1.78	0.80	22,779	14
Madison, WI	.	.	.	.	.	0.0	2.1	4.6	253	244	965	-2.12	0.42	0.86	19,086	14
Melbourne--Titusville--Palm Bay, FL	.	.	.	.	.	0.0	0.6	1.6	604	306	507	0.54	0.69	0.29	23,276	26

Appendix B

Urbanized Area	Number Reporting Commute Mode Choice in Rail Cities	% taking *Private Transport* to Work	% taking Non-Rail Public Transit to Work	% taking Rail Public Transit to Work	% taking Non-Motorized Modes to Work	Rail Transit Supply (10000 miles per km2)	Non-Rail Transit Supply (10000 miles per km2)	Density of Road Network (area of roads*100 per square mile of land)	Land Area (km2)	Population (1000's)	Population Density (people per km2)	Jobs-Housing Imbalance (Standardized)	Population Centrality (standardized)	City Shape	Average VMTs per Household	Number of Housholds with in Sample
Memphis, TN--AR--MS	43	93.0	2.3	2.3	2.3	0.0	0.8	3.7	883	825	934	0.27	-1.17	0.84	19,865	25
Miami, FL	88	81.8	6.8	1.1	10.2	0.7	3.8	6.0	913	1,915	2,096	-0.24	-0.26	0.04	16,695	59
Milwaukee--Waukesha, WI	.	.	.	.	.	0.0	1.7	4.1	1,326	1,226	925	-0.20	0.68	0.59	16,242	72
Mobile, AL	.	.	.	.	.	0.0	0.3	2.9	593	301	507	0.54	-0.42	0.05	19,900	21
Modesto, CA	.	.	.	.	.	0.0	1.3	6.8	135	231	1,708	-1.91	-0.65	0.52	14,150	15
Montgomery, AL	.	.	.	.	.	0.0	0.4	2.6	405	210	518	-0.91	0.06	0.60	16,005	14
Nashville, TN	.	.	.	.	.	0.0	0.4	2.8	1,252	573	458	-0.06	-0.94	0.83	23,023	40
New Haven--Meriden, CT	.	.	.	.	.	0.0	0.9	3.9	486	451	929	-1.85	2.37	0.51	18,914	244
New Orleans, LA	69	87.0	8.7	0.0	4.3	0.1	2.1	3.9	700	1,040	1,487	1.18	0.54	0.68	16,722	58
New York, NY	2141	63.1	8.6	20.5	7.8	5.7	3.0	5.3	7,683	16,044	2,088	0.87	2.02	0.73	13,364	1,489
Norfolk--Virginia Beach--Newport News,	.	.	.	.	.	0.0	0.4	2.0	1,719	1,323	770	-0.16	0.47	0.51	16,283	69
Oklahoma City, OK	.	.	.	.	.	0.0	0.2	4.4	1,675	784	468	0.43	-0.09	0.81	19,344	42
Omaha, NE--IA	.	.	.	.	.	0.0	0.9	5.1	500	544	1,089	1.10	-0.71	0.75	20,538	30
Orlando, FL	.	.	.	.	.	0.0	1.2	3.6	1,022	887	868	-0.05	-1.37	0.74	20,174	52
Pensacola, FL	.	.	.	.	.	0.0	0.3	4.0	402	254	630	1.29	-1.85	0.77	25,390	9
Peoria--Pekin, IL	.	.	.	.	.	0.0	0.5	3.5	334	242	725	-0.67	-0.36	0.76	13,402	13
Philadelphia, PA--NJ	363	81.8	6.3	5.0	6.9	1.4	2.1	4.1	3,015	4,222	1,400	-0.01	0.98	0.85	15,574	247
Phoenix--Mesa, AZ	.	.	.	.	.	0.0	0.9	4.5	1,919	2,006	1,045	0.65	-0.07	0.45	22,434	113
Pittsburgh, PA	130	80.0	10.0	1.5	8.5	0.1	1.9	3.4	2,015	1,679	833	0.11	0.84	0.61	16,459	99
Providence--Fall River--Warwick, RI--MA	.	.	.	.	.	0.0	1.2	3.8	774	846	1,094	-1.12	0.84	0.55	20,012	42
Raleigh--Durham--Chapel Hill, NC	.	.	.	.	.	0.0	1.0	4.4	456	306	671	0.04	-1.21	0.90	22,610	39
Richmond--Petersburg, VA	.	.	.	.	.	0.0	0.7	4.1	784	590	753	0.38	-0.32	0.82	14,733	27
Rochester, NY	.	.	.	.	.	0.0	1.1	3.7	570	620	1,087	-0.30	-0.08	0.77	21,140	41
Rockford, IL	.	.	.	.	.	0.0	0.6	4.6	236	208	881	-1.43	0.23	0.71	11,271	7
Sacramento, CA	80	92.5	3.8	0.0	3.8	0.2	1.1	5.0	865	1,097	1,269	0.39	-0.29	0.55	23,307	60
Salt Lake City--Ogden, UT	.	.	.	.	.	0.0	0.7	3.7	2,751	3,044	1,106	1.53	-0.94	0.46	18,671	40
San Antonio, TX	.	.	.	.	.	0.0	2.4	7.2	1,135	1,129	995	0.78	-0.69	0.80	21,500	58
San Diego, CA	219	90.9	1.4	0.9	6.8	0.2	1.6	4.2	1,788	2,348	1,314	2.61	1.94	0.36	24,248	137
San Francisco, CA	119	70.6	17.6	3.4	8.4	2.1	2.1	5.1	2,260	3,629	1,606			0.74		120
San Jose, CA	93	89.2	2.2	1.1	7.5	0.2	2.1	5.6	877	1,435	1,637	0.88	0.20	0.46	18,923	63

Appendix B

Urbanized Area	Number Reporting Commute Mode Choice in Rail Cities	% taking Private Transport to Work	% taking Non-Rail Public Transit to Work	% taking Rail Public Transit to Work	% taking Non-Motorized Modes to Work	Rail Transit Supply (10000 miles per km2)	Non-Rail Transit Supply (10000 miles per km2)	Density of Road Network (area of roads*100 per square mile of land)	Land Area (km2)	Population (1000's)	Population Density (people per km2)	Jobs-Housing Imbalance (Standardized)	Population Centrality (standardized)	City Shape	Average VMTs per Household	Number of Housholds with in Sample
Santa Rosa, CA	.	.	.	.	.	0.0	1.3	3.7	174	195	1,118	0.23	0.59	0.59	14,379	14
Sarasota--Bradenton, FL	.	.	.	.	.	0.0	0.5	3.2	500	444	889	0.05	2.06	0.22	20,730	24
Savannah, GA	.	.	.	.	.	0.0	0.6	2.3	390	199	509	-0.67	-0.46	0.74	7,577	13
Scranton--Wilkes-Barre-Hazleton, PA	.	.	.	.	.	0.0	0.4	3.1	521	388	745	-1.19	1.03	0.30	7,308	25
Seattle--Bellevue--Everett, WA	136	87.5	7.4	0.0	5.1	0.0	3.3	4.8	1,523	1,744	1,145	1.78	0.37	0.35	19,056	109
Shreveport--Bossier City, LA	.	.	.	.	.	0.0	0.6	3.2	379	256	676	0.54	-1.80	0.70	12,678	18
South Bend, IN	.	.	.	.	.	0.0	0.6	4.0	312	238	763	-0.83	0.48	0.98	12,363	13
Spokane, WA	.	.	.	.	.	0.0	2.5	5.1	294	279	948	0.75	0.97	0.69	13,035	20
Springfield, MA	.	.	.	.	.	0.0	0.7	3.5	782	533	681	-1.55	0.55	0.55	17,179	26
Stockton--Lodi, CA	.	.	.	.	.	0.0	1.1	6.0	191	262	1,371	-0.95	-0.03	0.67	23,273	19
Syracuse, NY	.	.	.	.	.	0.0	1.4	4.6	346	389	1,124	0.46	1.20	0.65	16,756	21
Tacoma, WA	.	.	.	.	.	0.0	1.9	4.2	603	497	825	1.69	-0.63	0.79	20,469	19
Tampa--St. Petersburg--Clearwater, FL	130	91.5	2.3	0.0	6.2	0.0	0.5	3.7	1,683	1,709	1,015	0.84	-0.72	0.99	15,344	115
Toledo, OH	.	.	.	.	.	0.0	0.9	4.9	501	489	977	-1.18	-0.45	0.81	16,687	24
Trenton, NJ	23	87.0	4.3	0.0	8.7	1.6	4.3	4.8	248	299	1,203	-0.20	0.05	0.62	20,514	14
Tucson, AZ	.	.	.	.	.	0.0	1.3	7.8	639	579	907	-0.41	-0.94	0.80	16,925	41
Tulsa, OK	.	.	.	.	.	0.0	0.5	6.0	788	475	602	0.59	-0.16	0.81	21,532	25
Utica--Rome, NY	.	.	.	.	.	0.0	0.5	3.1	237	159	669	-1.86	2.73	0.34	24,325	6
Washington, DC-MD-VA	361	80.3	8.0	5.0	6.6	1.7	1.9	4.5	2,447	3,363	1,375	1.20	0.37	0.82	19,991	208
West Palm Beach--Boca Raton, FL	.	.	.	.	.	0.0	0.4	3.9	794	795	1,001	0.41	1.26	0.28	22,210	33
Wichita, KS	.	.	.	.	.	0.0	0.6	4.3	374	339	905	0.84	-1.36	0.96	16,024	19
Wilmington--Newark, DE--MD	.	.	.	.	.	0.0	1.2	4.5	487	450	924	-1.11	0.97	0.44	13,478	25
Worcester, MA--CT	.	.	.	.	.	0.0	1.0	3.1	359	316	878	0.41	3.03	0.70	20,711	9
Youngstown--Warren, OH	.	.	.	.	.	0.0	0.3	5.8	433	362	834	-1.03	-0.11	0.44	21,251	25

Appendix C
Calculation of Fixed Costs of Vehicle Ownership and Average Fuel Economy

To calculate the fixed costs of vehicle ownership we divide the households in our sample into three income groups (0-29,999; 30,000-59,999; 60,000+) and calculate an average cost of vehicle ownership based on the makes, models and vintages of automobiles owned by households in that group.

In general, the cost of owning a car of vintage v in 1990 would be the cost of buying that car in 1990, P_v, times the sum of the rate of interest (r) and the rate of depreciation (d), plus insurance costs, I_v.

Fixed Costs of Car Ownership = $(r + d) P_v + I_v$.

Unfortunately, our data on insurance costs, average insurance expenditures per auto (Insurance Information Institute), are available only at the state level and do not vary with make, model or vintage. We assume $r = 0.10$ and $d = 0.05$. To compute an average value of P_v for each income group we divide the vehicles owned by each income group into three vintage categories—New (1991-1987), Medium (1986-1980) and Old (1979-1975). As Table A.1 indicates, higher income households are more likely to own newer cars.

Table A.1. Car Vintage by Income Class (%)

	Income		
Vintage	*High*	*Medium*	*Low*
Old	11.9	18.7	27.4
Medium	39.8	43.6	46
New	48.3	37.4	26.6

For each of the 9 vintage/income groups in Table A.1 we selected the 10 make/model combinations owned by the greatest number of households. An average value of P_v was calculated by weighting 1990 *Kelley Blue Book* suggested retail prices for each of the 10 make/model combinations by the share of consumers buying each model. The resulting average prices are shown in Table A.2.

Table A.2. Average Car Price by Vintage and Income Class ($)

	Income		
Vintage	*High*	*Medium*	*Low*
Old	1645	1540	1528
Medium	4225	3721	3538
New	12629	10568	9296

The average price for each income group was computed by weighting P_v for each vintage by the fraction of the income group buying that vintage (Table A.1).

Average fuel economy was calculated in a similar fashion, based on the fuel economy of top ten selling make/model combinations in each income/vintage class. The average miles per gallon for each income group was computed by weighting the numbers in Table A.3 by the fraction of the income group buying that vintage (Table A.1).

Table A.3. Average Miles per Gallon by Vintage and Income Class

	Income		
Vintage	High	Medium	Low
Old	14.2	14.2	14.2
Medium	22.5	24.6	22.5
New	24	24	25.5

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