Does TOD need the T?

Auto use, residential sorting, and access to rail

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For presentation at the 2013 Annual Meeting of the Transportation Research Board
Draft of November 15, 2012

Acknowledgments: A number of people contributed to the research study upon which this article draws. Marc Weiner coordinated the household survey, with the able assistance of Orin Puniello. Marc also advised on the questionnaire design. The mailings and data entry were carried out by ABT/SRBI, lead by Chintan Turakhia and coordinated by David Ciemnecki. Project manager Stephanie DiPetrillo designed the physical layout of the survey, selected the new TOD portion of the survey sample, managed the field survey of on-street parking, and drafted the final report from which some of the "Data Collection" section was extracted. Research funding for these tasks was provided by the New Jersey Department of Transportation with pass-through research funds from the Federal Transit Administration. In addition, Dan Tischler coded verbatim occupational responses into standard classification categories. Nick Klein carried out the construction of most spatial measures in GIS, except for the grocery store counts, which were carried out by Matt Brill. Thanks to Mike Manville, Robert Noland, and Robert Cervero for their helpful comments on previous drafts.

Abstract

Smart growth planning often focuses on building new housing near rail stations, on the assumption that transit-oriented development can reduce driving and therefore mitigate climate change, pollution and congestion. But research has rarely investigated how transit-oriented development affects auto use—or asked whether new development should be oriented away from autos, rather than toward rail.

This study addresses two questions. First, do households choosing new housing near rail stations have different patterns of auto ownership and use? Second, are those differences a result of rail access, or other factors associated with rail access? Previous studies have not used comparable data to compare nearby and farther away housing units; have lacked data on parking supply; have not controlled for characteristics of the housing itself, particularly the age of the housing; and have generally failed to account for how residential choices may affect TOD housing outcomes.

I surveyed over 1,100 households within two miles of ten rail stations, and conducted a field count of over 6,200 on-street parking spaces on 818 block faces near the stations. The household survey collected information on housing characteristics, parking, travel, and household demographics as well as stated residential choice criteria to control for heterogeneity in preferences. The survey data were geocoded and joined to on-street parking supply data and other spatial data from secondary sources. I used regression analysis to examine how housing, parking, neighborhood and subregional spatial characteristics are correlated with automobile ownership, commuting, and grocery trips.

Auto ownership and use is much lower among households living in new housing near rail stations, but these differences are not explained by rail access. Off- and on-street parking availability, housing type and tenure, local and subregional density, and bus service are much more highly correlated with residential choices and subsequent auto ownership and travel. Rail access is associated with lower auto use when *combined* with factors like parking supply and housing type, but rail by itself has little explanatory power.

The details of TOD matter, and some of the things that “work” about TOD have little or nothing to do with rail access by itself. Planners should broaden efforts to develop dense, mixed-use housing beyond rail station areas. Denser housing development coupled with good management of automobile parking and improved bus service could be more -effective, and less expensive, than a development policy oriented around rail stations.

Rail access, transit-oriented development, and auto use

Many urban planners advocate transit-oriented development (TOD), which often means new housing near rail stations. TOD is a hallmark of "smart growth" land use and transportation planning, and one of its purposes is to reduce the local and global environmental impacts of auto use. This planning strategy has two important premises: first, that households living in new housing near rail stations drive less; and second, that the proximity to rail—as opposed to other attributes of TOD—is responsible.

There are reasons to doubt these premises. Building new housing near rail could affect auto ownership and use through multiple pathways, not only proximity to transit. Higher development density, less parking, and the presence of more shops and services nearby could all induce residents of TODs to drive less. And residential choice is an important part of the story as well. New TOD housing could attract affluent residents with a high rate of auto use. On the other hand, it could attract those who want to drive less but have a hard time doing so in conventional developments.

Researchers sometimes refer to this process of choosing where to live as "residential self-selection," a statistical term that denotes a problem in correctly estimating the independent effect of a "treatment." For many transportation researchers, therefore, controlling for self-selection is a vital part of evaluating transit-oriented development. This article takes a different view. If we are interested not just in the "independent" effect of TODs, but also in how residential choices allow people to act on their travel preferences, then correcting for self-selection misses the point (Levine 1998; Naess 2009). Residential choices may expand when new housing is built near transit. Perhaps households who previously had wanted to drive less but could not find housing that allowed them to will then be able to act on those preferences. This is a phenomenon to be measured, not controlled for.

This study uses data from New Jersey to ask whether and how the automobile use of households choosing recently-built housing near rail stations differs from households in older housing, or in new and older housing farther away. I focus on three measures of automobile use—ownership, commute mode, and grocery trips. I surveyed 1,134 households within two miles of ten rail stations, and conducted an on-street parking audit of 818 blocks within a quarter mile of those stations. The data from the survey and parking audit were joined with spatial measures of retail, employment, population, grocery stores, and bus stop density at the neighborhood and subregional level.

In this dataset, new housing near rail has much lower rates of auto ownership, commuting, and grocery trips compared to new housing farther away—an unsurprising result. However, rail access is not independently correlated with auto ownership or use when controlling for on- and off-street parking supply, population density, and bus access, among other factors. These results suggest that TOD may not need its "T": that advocates for using the built environment to minimize automobile externalities should push for NAOD—non-auto-oriented development.

Previous studies of TOD and travel

The term "transit-oriented development" sometimes refers to buildings near transit, sometimes to clusters of buildings near transit, and sometimes to larger areas of up to a half-mile radius around a transit stop (typically, a rail stop) that meet some criteria of density, mixed uses, pedestrian amenities, and physical designs that are thought to support the use of alternatives to the auto (e.g., Calthorpe 1993b). Many TOD advocates have distinguished between "transit-oriented" and "transit-adjacent" development; in other words, between developments *designed* for transit, and developments that happen to be near it. Transit-oriented development, for example, might have better pedestrian amenities, more walk-accessible shopping, and lower parking requirements than transit-adjacent development (e.g., Belzer and Autler 2002; Cervero, Ferrell, and Murphy 2002).

This definition of transit-oriented development, however, suggests the term may be a misnomer. Places with better pedestrian amenities and less parking are not by definition oriented around transit; they may be *not* oriented around driving, or auto-disoriented. If one important purpose of a TOD is to increase rail use, then the presence of rail transit is imperative. If the main travel purpose of a TOD is to reduce driving, it may be enough to simply have fewer parking spaces and more places to walk. The United States does have neighborhoods that meet this description, but they are relatively few and they tend to be old. People who buy or rent older housing might differ systematically, in income or tastes, from those who occupy new housing.

Studies have long found that TODs have substantially higher rates of transit ridership, particularly rail ridership (Cervero, Ferrell, and Murphy 2002, p 40-42). Fewer studies have compared the auto ownership and use of those living in TODs to those living elsewhere. These studies have yielded mixed results. A study of selected transit-oriented housing developments in California in 2003 found that 72 percent of survey respondents commuted in personal vehicles; the survey did not include a control group, but the rate was lower than the Census rate for surrounding cities of 90 percent in 1999 (Lund, Cervero, and Willson 2004). A study of 17 built transit-oriented developments in four US urban areas was conducted using vehicle counters in driveways, finding 44 percent fewer vehicle trips than the published rates in the Institute of Transportation Engineers manual (Arrington and Cervero 2008). The study did not directly compare similar developments without transit service, however; and the lower observed auto use in comparison to ITE rates could be partly due to factors that inflate the ITE estimates (Shoup

2005, Chapter 2). A simulation model conducted for Austin, Texas, found there was very little modal shift associated with transit-oriented development, although there was lower vehicle mileage because trip distances were shortened (Zhang 2010). Conversely, an survey of San Diego and the San Francisco Bay Area, with over-sampling of selected rail station areas, found that proximity to a heavy rail station was associated with higher vehicle mileage (Chatman 2008). A recent study of Manhattan and Hong Kong found that rail station ridership was positively associated with the auto ownership of households living nearby (Loo, Chen, and Chan 2010).

Studies not only specifically about TOD but also about the built environment's impacts on travel are highly relevant to this question, because these studies tend to control for multiple factors simultaneously and sometimes include distance to transit as an explanatory factor. A recent meta-analysis of this research found six studies that used vehicle miles traveled (VMT) as a dependent variable and distance to transit as an independent variable (Ewing and Cervero 2010). The average elasticity of VMT with respect to proximity to transit was very small, at -0.05, and likely not statistically significant, though significance was not estimated in the study.

In summary, while a number of studies have investigated the role of rail access in explaining travel patterns, findings have varied and the studies have tended to speak only indirectly to the question addressed here. Many studies have focused on transit ridership rather than auto ownership or use. Other studies looked only at households living near transit, or made comparisons between survey data and Census data. Most studies do not include information on characteristics of the housing units themselves, which could affect residential choices that lead to differences in travel patterns—particularly the age of the units. And few or possibly no previous studies include information about on- or off-street parking when investigating auto ownership and use in TODs.

Data collection

Answering these questions requires a survey that captures a sufficient number of near-station households *and* control households farther away. It also requires an oversample of new housing, since most housing near transit is not new so a representative sample will not capture enough to make valid inferences about new versus older housing. I selected ten areas within a two-mile radius of ten rail stations in New Jersey in which to conduct a mail survey of households, some of them living in purpose-built TODs as well as those in new and older housing nearby and farther away from rail. On-street parking supply and use was observed in the field for a quarter-mile radius around the stations. The analysis dataset was constructed by merging the household survey and the on-street parking data, and then joining to that dataset neighborhood and subregional spatial measures constructed near respondent households using secondary data sources in a geographical information system. These stages are described briefly below; more details are available elsewhere (Chatman and DiPetrillo 2010).

Study areas

Among New Jersey's 208 rail stations, only those with at least 800 residents within walking distance were considered, eliminating about a quarter of station areas from consideration. The main issue in choosing the stations was ensuring that the survey areas within a two mile radius of selected stations would yield sufficient variation in housing age, housing density, and distance to rail to ensure statistically robust comparisons, while preserving representativeness of the station area sample. The stations selected were Morristown and South Orange on the Morris & Essex Line, Perth Amboy and South Amboy on the North Jersey Coast

Line, Rahway and Trenton on the Northeast Corridor line, Westfield and Cranford on the Raritan Valley Line, and 2nd Street and Essex stations on the Hudson-Bergen Light Rail line (Figure 1). The two-mile-radius area around these ten stations includes about 740,000 people, or about nine percent of the population of the state. The study area has generally better transit access and higher population density than the rest of the state.

[Figure 1 about here]

Household survey

I constructed a sample of 5,000 housing units within the ten station areas. I began with a list of 1,073 units in recently built or substantially renovated multifamily housing developments near the stations. The remainder of the sample was drawn from a list of households based on US postal service addresses in zip codes within two miles of the stations. This list was geocoded, and the distance from each housing unit to each of the selected stations was calculated. Keeping a roughly equal pool for each station, I then randomly sampled 2,427 housing units within a quarter-mile airline distance from the stations, and an additional 1,500 units between a quarter mile and two miles away. Of the total sample of 5,000 units, about ten percent turned out to be unusable because of vacancies, bad addresses, and the like, leaving an adjusted sample size of 4,503.

The survey questionnaire focused on housing unit characteristics, on- and off-street parking, work and non-work travel, household characteristics, and residential location criteria (see Appendix). Many of the questions were slightly modified versions of questions appearing on the American Community Survey of the Census, the Nationwide Household Transportation Survey, the American Housing Survey, and previous surveys by the author. The questionnaire was pretested, and revised, prior to fielding from June 3 to August 26, 2009. Five recruitment mailings were sent: an invitation letter with questionnaire, a reminder postcard, two subsequent letters with replacement questionnaires to non-respondents, and a final “last chance” contact letter, in a modified version of the Dillman “total design method” mail survey protocol (Dillman, Dillman, and Makela 1984; Dillman 1978). In total, 1,143 completed surveys were received, for a response rate of 25.4 percent.

Parking audits

On-street parking observations were recorded for blocks fitting at least 50 percent within a quarter mile airline buffer of the stations. Blocks were equally divided among three trained student surveyors, with each student covering approximately one-third of the overall study site. In the field, parking spaces were recorded as they appeared on the block with notations used to designate many variables characterizing the spaces. Field workers observed during the evening peak parking period, between 5 pm and 8:30 pm, collecting data on the number of on-street spaces by type (marked and unmarked), occupancy, parking duration limitations, space type (including limitations for disabled use and other permit holders), time restrictions, street cleaning, and no-parking periods, for 6,237 parking spaces on 818 street segments. The parking data were collected from June 19 to July 24, 2008, a year prior to the household survey (the delay was due to an interruption in research funding).

These field observations of parking were merged with a street segment map. Information about the street segments was later aggregated to construct measures of on-street parking density around the homes of 532 of the 1,134 surveyed households, those living within a quarter-mile airline distance of the ten selected rail stations. Some of those units are farther than 0.4 network miles from the station even though they are within 0.25 airline miles. In addition, there were some households included in the survey that lived within walking distance of rail stations that were not part of our parking audits. Thus not all households within walking distance of a rail stop have on-street parking data, and some households just outside walking distance do have on-street parking data available.

Of the various possible on-street parking measures, I used overnight parking spaces per road mile within a quarter mile of respondent homes. Overnight parking supply is defined as all parking spaces that could be continuously occupied for free, without a permit, and without time restrictions from 8 pm to 8 am.

Secondary data sources and variable construction

In conducting data description and analysis, I distinguish new from older units, and those within walking distance to rail from those farther away. "New" housing was defined as housing that had been built within seven years of the survey, based on respondent reports as well as independently collected information about selected buildings near the stations.[1] I defined "walking distance" as within being 0.4 miles as measured along the local street network, along which sidewalks were universally available. This definition is bit shorter than Calthorpe's (1993a) 2,000-foot definition of walking distance for TODs, and for most houses, was roughly equivalent to a quarter-mile airline distance.[2] A continuous variable for distance to rail was also included.

Residential location criteria variables were constructed using answers to answers to the question, "Please rate the top three factors that attracted you to this neighborhood." A dummy

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[1] Housing age was reported by survey respondents and supplemented with information about the year of development for those multifamily projects that were in the initial TOD housing database described above. Almost 20 percent of respondents reported that they did not know the age of the unit they were living in, or did not answer the question; only 6 percent of those were in multifamily units known to be new. I assume the remaining units were constructed 8 years or longer ago.

[2] Among the 1,134 households, 40 different "nearest" rail stations were represented. This is because the two-mile radius survey areas around the ten selected stations included households with a different nearest rail station: 13 percent of all respondents, and 6 percent of respondents within walking distance of the selected station. The data description presented in this article differs slightly from that in Chatman and Dipetrillo (2010) because this distance correction had not been made, and also because airline distance rather than network distance was used in that previous report.

variable was set equal to one for any factor ranked by a respondent, regardless of rank value. There were a dozen residential location criteria variables.

An indicator of off-street parking scarcity was set equal to one if the respondent reported having less than one off-street parking space per adult in the household, and zero otherwise. I also included a variable representing the interaction between on- and off-street parking. If there is little off-street parking but ample on-street parking, or if there is plenty of off-street parking but no parking on the street, there should be no difficulty in parking a car. The variable was set equal to one if the household had fewer than one off-street parking space per adult *and* if on-street overnight parking availability was below the observed median value of 138 overnight parking spaces per road mile.

I constructed a number of other local and subregional built environment measures to supplement the analysis. The population density in Census blocks within a quarter mile of each respondent's home was calculated from data on population and land area of the blocks from the 2000 Census, using a geographical information system to select Census blocks whose centroids fell within a quarter-mile radius of respondent addresses. Employment density and retail employment density was constructed in a similar fashion using data from the Census Bureau's 2008 Longitudinal Employer-Household Dynamics (LEHD) dataset. The density of bus stops near home was calculated using bus stop locations from NJ Transit provided as of 2010. Network distance to the Manhattan CBD, defined as the nearer of Grand Central Station or Penn Station, was calculated using a street file and network analysis routine. I also created measures of population density, employment density, and bus stop density at the subregional level, using the 2005 to 2007 pooled American Community Survey Public Use Microdata Sample for the Public Use Microdata Areas within which the households lived.

Finally, for the grocery trip models, data on grocery stores, using NAICS code 445110, were downloaded from referenceusa.com, geocoded to the address level, and aggregated to the quarter-mile radius around respondent homes. I tested several different measures: number of stores, number of grocery employees, and grocery store revenue, measured at the quarter-mile, half-mile and one-mile radii. The simplest and most intuitive measure, the number of grocery stores within a quarter mile of home, was also the most highly significant and negatively associated with the number of auto-based grocery trips, so it is the measure used here. I also tested whether farther-away grocery stores might induce more auto-based grocery trips, but found no significance.

Table 1 (below) shows averages and standard deviations for the main variables used in the analysis.

[Table 1 about here]

Observed differences according to rail distance and housing age

Within the respondent pool, those living in new housing near rail stations had lower auto ownership, lower auto commuting, and lower auto-based grocery trip frequency than those living in either new or older housing farther away—and in most cases, lower than households living in older housing near the same rail stations (Table 2, below).

[Table 2 about here]

The differences shown in Table 2 are consistent with the conventional claim that transit-oriented housing development is likely to cause fewer problems with traffic and parking. Remarkably, households in newer housing near rail stations use and own autos less not just compared to households in new housing farther away, but also compared to those in older units near rail. Just 36 percent of respondents living in new housing near rail reported commuting to work via singly-occupied vehicle in the previous week, compared to between 59 and 67 percent of the other households in the sample. This is notable and important because one might expect newer housing to be more expensive and therefore for its occupants to be more likely to use autos.

What might explain these differences? There are a number of possibilities, some of which can be accounted for in controlled analysis using observable data, and some of which are much harder to control for. Perhaps the housing has less parking, perhaps the neighborhoods are more conducive to alternative modes other than rail (like biking and walking), perhaps smaller, younger households who are less reliant on autos live there, perhaps such housing is for rent and therefore attracts those with fewer assets (including fewer autos).

Table 3 (below) shows some differences in some of these additional observable explanatory factors, including tenure, size of housing, parking supply, neighborhood population density, and neighborhood bus stop density, and whether the differences are statistically significant. The tenure and type of housing could play a role in the travel patterns of households choosing housing units. Both rental properties and smaller units may attract households who are younger, of lower income, and who may not have children. All these characteristics may be correlated with lower auto use. Rental status is much more common in new housing near rail, making up fully 57 percent of such housing, compared to just 16 percent of those in new housing outside walking distance (Table 3, column 1). 48 percent of older housing near rail is rental, and 29 percent of older housing farther from rail is rental. At the same time, whether owned or rented, *all* newer housing regardless of location is much more likely to be in smaller units in this dataset (Table 3, column 2). Fully 98 percent of new housing near rail consists of apartments, condominiums, townhouses, or rowhouses, while new housing farther from rail also has a high share at 71 percent, higher than older housing near rail (62 percent) and older housing farther from rail (37 percent).

[Table 3 about here]

On-street parking availability in the neighborhood, and the number of off-street spaces available to housing units, could also affect automobile ownership and use. Off-street parking availability is lower on average in new housing near rail than in housing farther from rail (Table 3, column 3). At the same time, on-street parking is *more* available to newer units (column 4).

Combined low on- and off-street parking could be particularly influential. The difference between new and old housing on this measure is large (17 versus 12 percent) but the difference is not statistically significant (column 5).

The larger neighborhood spatial context could also play a role. I present two measures to illustrate this: population density within 1/8 mile and the number of bus stops within one mile (Table 3, columns 6 and 7).[3] Population density for both new housing and old housing near rail—and, notably, for older housing farther from rail—has higher population density (in the 13,000 residents per square mile range) than does new housing farther from rail (Table 3, column 6). As for bus stops, new housing near rail averages more than 150 stops within a mile, which is much higher than older housing near rail among respondents to the survey. Older housing farther from rail actually has more bus stops nearby than does new housing farther from rail. This interesting result is partly driven by the fact that there is more new housing in the northern

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[3] Of several spatial areas in which I measured them, the eighth-mile radius for population and the one-mile radius for bus stops were most highly correlated with auto ownership and use.

station areas in and near Jersey City, where bus service is denser **[this seems self-contradictory]**. [4]

The fact that those living in newer housing near rail have much lower solo-commuting and use of autos for grocery trips than the other strata, including those in older housing near stations, is all the more notable given the fact that respondents living in new housing had substantially higher household incomes and those in older housing near stations had the lowest household incomes (Figure 2, below). Higher income has been shown to be associated with greater auto ownership and use.

[Figure 2 about here]

Race/ethnicity is also correlated with auto ownership and use, and may be correlated with household location as well. In our respondent pool, 76 percent of households reported as White, 13 percent as Black, 6 percent as Asian, 1 percent as Native American, and 3 percent did not answer the question. Hispanic status, an overlapping category, was reported by 14 percent of respondents. Blacks and Asians reported having fewer vehicles per adult than Whites. Asians had lower commuting by car and lower frequency of auto trips to the grocery store than Whites. There were no statistically significant auto ownership or use differences associated with Hispanic status. Respondents living in new housing near a rail station were more likely than others to be non-white. A higher occupancy of new housing by minority racial/ethnic groups is consistent with the fact that most population growth in the state over this recent period has been driven by Asian and Hispanic immigration (Chatman and Klein 2009), though this theory cannot be explicitly tested because nativity status is unavailable in the dataset. Those reporting as Asian were particularly much more common in new housing near stations, making up 16 percent of

[4] As noted previously, station-area fixed effects are insignificant when spatial measures are included, and distance to CBD is also included in the models shown later.

respondents there compared to 9 percent in new, farther away housing, and 3 to 4 percent of respondents living in older housing.

What causes lower auto use in new housing near rail?

To investigate why auto ownership, auto commuting, and grocery trips by auto vary so markedly by housing age and rail station proximity, I carried out a series of multivariate regressions. For each of the three tables below I first present a regression with just rail proximity and age of housing; second, a regression adding other housing unit, parking, and spatial characteristics; and, third, a regression adding demographic characteristics and residential choice criteria. [5] I include a fourth regression restricted just to households within walking distance of a rail station. In addition, for auto commuting and grocery trips, I carried out a fifth model including auto ownership as an (endogenous) explanatory variable. The purpose of this series of regressions is to show whether and how associations with distance to rail and age of housing are affected when other factors are accounted for.

There are other explanations for the observed lower auto ownership and use of residents of new housing near transit that are harder to directly test. For example, perhaps recent movers to TODs optimize their commutes around transit in the short run, but in later years as their work locations shift, they begin to drive. It is also possible that changing lifestyle preferences among younger people explain some of the correlation of TOD locations and lower auto use, or that shifts in the housing and labor markets, and the recent economic downturn, are more keenly felt by those recent movers who are more likely to save money by owning and using autos less.

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[5] When independent variables of interest were statistically insignificant in the presence of variance inflation, I removed other collinear variables to see if significance occurred once variance inflation was reduced. Statistical significance was generally unaffected, except for the spatial variables; the set of spatial variables varies slightly for each dependent variable. Household income thresholds included in the model also varied due to different patterns of statistical significance.

These explanations may explain any residual significance of housing age and transit proximity that are left over after controlled analysis on observable factors, or they may in fact be correlated with those observable factors, such as income and preferences.

Model 1 in each table includes the network distance to rail, whether the rail station was within walking distance, and whether the unit was seven years old or newer. This initial model estimates the size and significance of the differences between housing units of different age and distance to rail in auto ownership, auto commuting, and grocery trips by auto.

Model 2 in each table adds controls for the type of housing (attached vs detached), housing tenure, off-street parking scarcity, overnight on-street parking supply,[6] low on- and off-street parking, and built environment characteristics[7] including bus stop density, employment density, retail density, and population density, measured both for nearby Census blocks and for the subregion (PUMA). Also, the number of grocery stores within a quarter mile is included in the grocery auto trip frequency models.

Model 3 in each table adds household size, household income, indicator variables to denote single-parent families and the presence of children in the household, the race/ethnicity and Hispanic status of the respondent, the respondent's occupation and employment status, and self-reported residential choice criteria. Household income is represented as a linear variable and

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[6] Only 532 households had observed on-street parking data. The lack of data for the remaining households was handled using the missing value dummy variable approach (Allison 2002) and also implicitly tested for robustness in model 4 of each of the tables, restricted to near-station households where almost all households had on-street parking observed. Missing responses for other variables, such as housing type and tenure, were also handled with this approach. Those variables are shown in the tables, when significant, but are not discussed.

[7] In analysis not shown here I also ran a series of regressions including station-area "fixed effects:" dummy variables representing each of the ten station areas from which the sample was taken to test for possible unobserved heterogeneity in built environment characteristics. These variables were statistically insignificant when the built environment measures were included.

also with indicator variables to search for nonlinear income effects, following the categories in which respondents reported their household income on the survey.

In the first models I deliberately do not control for demographics and preferences. Different houses and neighborhoods may attract households with different levels of and preferences for auto ownership and use. The second model in each of the tables implicitly includes these residential choice effects, while the third model in each of the tables, controlling for demographic characteristics and location preferences, is meant to estimate the independent effects of transit, housing unit, and neighborhood characteristics on travel patterns regardless of the observed characteristics of the households living there.

The results shown in models 2 and 3 in the tables below are meant to denote a range of possible travel impacts of housing characteristics. Which sets of effects are more reliable depends on how much of the effects associated with preferences and residential choice can be expected to occur in the future; but the answer is likely somewhere in the middle of these two effects.

The fourth model in each of the tables replicates the variables used in the second, but restricts the analysis to households within walking distance of rail to explore whether rail access might interact with housing unit and built environment characteristics to affect auto ownership and use.

There is a fifth model in the tables for auto commuting and auto-based grocery trips. That model adds auto ownership as an explanatory variable, and is used to explore whether the main effects of the other independent variables appears to be mediated through auto ownership; for example, whether rail proximity affects auto commuting only by affecting auto ownership, or independently of its effects on auto ownership.

Auto ownership

I measured household vehicle ownership using the number of vehicles divided by the number of adults in the household, which I refer to here as "per capita auto ownership".[8] This measure is readily adaptable to multipliers based on occupancy factors such as household size. In the first model (Table 4, column 1), per capita auto ownership is regressed on distance to rail and the age/walking distance threshold variables, using ordinary least squares. Each additional mile from a rail station is associated with an additional 0.09 vehicles per adult in the household, on average. Part of this effect is, again, presumably a result of sorting by household characteristics like income and occupation. The coefficients on the next three variables show that older housing, whether within walking distance of a rail station or farther away, is associated with fewer cars per capita than is new housing outside walking distance. The coefficients together suggest that new housing near rail is associated with 27 percent lower auto ownership than new housing farther away. For households near rail stations, newer houses appear to have fewer autos per adult (-0.18 vs -0.11), although the apparent difference is not statistically significant.

[Table 4 about here]

The second vehicle ownership regression (Table 4, column 2) introduces housing unit, parking, and built environment characteristics to explore the reasons for this strong association between rail proximity and auto ownership. Notably, with these other factors included, that the correlation of vehicle ownership with rail proximity and housing age markedly decreases and is

[8] I also explored other several other measures of vehicle availability, including vehicles per household, whether the household was a zero-car household or a one-car household, and whether there is less than one car per adult in the household. The results were most robust and significant with the vehicle-per-adult models. This per-capita (per-adult) model is also better because it controls for differences in household size that might be correlated with rail proximity.

no longer statistically significant. Among the most powerful variables in this model are off-street parking scarcity, and low on- and off-street parking availability. Houses with fewer than one off-street parking space per adult have 0.16 fewer vehicles per adult, while those with both low on- and off-street parking availability have an additional 0.14 fewer vehicles per adult. Rental housing is also associated with 0.13 fewer vehicles per adult. Of the built environment variables, the most significant is the number of bus stops within a mile of the home. The coefficient of -0.0079 implies that a one-standard-deviation increase in bus service (the equivalent of 118 bus stops in the mile radius around home) is associated with 0.09 fewer vehicles per adult.

The third model in this set adds in additional controls for demographics and preferences of households (Table 4, model 3), accounting both for the fact that TODs may attract previous transit users as well as the fact that they may enable households moving in to use alternative modes more. A number of coefficients on the newly entered demographic and preference variables are large and significant in this model, but I focus on the housing unit and spatial characteristics as they are the most policy-relevant. Rail proximity remains insignificant and small in comparison to other independent variables. The coefficient on off-street parking scarcity is reduced from -0.16 to -0.11 vehicles per adult, but remains economically substantive, representing a 13 percent reduction in auto ownership at the mean. The interaction of low on-street and low off-street parking availability has approximately the same magnitude relationship as in the previous model, reducing from -0.13 to -0.11 cars per adult. The coefficient on townhomes and apartments increases from -0.065 to -0.13; the increase appears to be due to household size being controlled, since larger households have fewer cars per adult in the household (because larger households can more easily share cars). The effect associated with townhomes and apartments is unclear. They might have off-street parking that is less convenient (farther from the unit), or other factors that are not observed. Job density in the half-mile radius has a slightly larger correlation in this model, and becomes statistically significant. The measured impact of bus stop density declines about 25 percent, but also remains significant. In short, the third auto ownership model suggests that sorting by income, household size, and housing preferences apparently does explain a significant share of the correlation of auto ownership with off-street parking availability, size of the unit, bus access, and built environment characteristics—but those measures remain significantly associated with lower auto ownership, in marked contrast to rail proximity.

Limiting the analysis to households near stations enables a more explicit test of how rail station access may interact with other factors (Table 4, column 4). The combination of low on- and off-street parking availability apparently has stronger effects *combined with* rail station proximity: there are 0.24 fewer vehicles per capita when the analysis is restricted to near-station households, almost double the relationship when not considering distance to rail. The coefficient declines to 0.17 vehicles per adult when accounting for demographic characteristics and household residential location criteria.

Auto commuting

Table 5 presents a logit model of the decision to commute by automobile. Of the dataset of 1,134 respondents, 810 reported that they worked part or full time in the previous week, and of those, all answered the subsequent question about how they got to work. I defined "auto" as a singly-occupied personal vehicle.[9] Coefficients are exponentiated for ease of interpretation; the increment greater or less than one can be interpreted as a percentage increase or decrease in the probability of commuting via a singly-occupied vehicle, holding other variables at their means.

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[9] Carpools are excluded because they are relatively efficient and less-polluting on a per capita basis, although there were similar results when analyzing single-occupied vehicles plus carpools.

Model 1 (Table 5, column 1) shows that each mile from a rail station is associated with a 74 percent increase in the odds of commuting via auto; and households living in new housing within walking distance of a rail station are only 43 percent as likely to commute via auto compared to households in new housing farther away.

[Table 5 about here]

Model 2 introduces housing unit, parking availability, and built environment variables (Table 5, column 2). The rail proximity coefficient shrinks from 1.72 to 1.32 and loses statistical significance. This is likely because housing closer to stations has lower off-street parking availability, higher employment and population density nearby, and more bus service, and is more often rented, not owned. At the same time, a clearer distinction between older and newer housing emerges. In this better-controlled model, households living in older housing are *more* likely to commute via car than those living in newer housing, all else equal. Perhaps a substantial share of the households occupying new housing have chosen where to live based on seeking alternative mode commutes to their work; while those occupying older housing are more likely to have had changes in the locations of work since their most recent move, and therefore to have to rely more on autos given the relatively sparse transit network. Meanwhile, having less than one off-street parking space per adult in the household is associated with just 62 percent as much auto commuting as those with more off-street parking.

In the third auto commuting model (Table 5, column 3), most of the demographic characteristics are not significant but many of the preference variables are. Seeking proximity to job, leisure, schools, or highways is positively associated and seeking access to transit negatively associated with auto commuting. The positive association between older housing and auto commuting loses statistical significance, though remaining relatively large in magnitude, at a 60 percent higher likelihood compared to new housing. Having scarce off-street parking remains very significantly associated with lower probability of commuting via auto, increasing slightly from a 38 percent to a 44 percent lower likelihood.

To better investigate how parking and other factors may interact with rail station access, I re-estimated model 2, restricted to commuters within walking distance of rail (Table 5, column 4). In this model off-street parking is by itself no longer independently significant. But near-station households with both low on- *and* off-street parking have auto commuting just 40 percent as high as other households, controlling for other factors. Few of the remaining variables in model 2 are significant, with the exception of higher subregional employment density being associated with less auto commuting.

Finally, I estimated a model with the addition of a single explanatory variable to model 3, the number of vehicles per adult (Table 5, column 5). Deciding how many vehicles to own is part and parcel of the commuting decision, and for this reason, adding auto ownership as an independent variable to the model will tend to bias the coefficient estimates for the other independent variables, resulting in underestimates of their true correlations with the probability of auto commuting. But including vehicles per adult does illustrate how parking supply, housing characteristics, and transit proximity are directly correlated with auto commuting, and indirectly correlated via auto ownership. The number of vehicles per adult has an odds ratio of 7.59, controlling for other factors, while parking loses significance, suggesting that its effects on auto commuting are felt via the auto ownership link.

Grocery auto trip frequency

Rail access could directly and indirectly reduce driving to the grocery store by reducing auto ownership; by lowering the rate of auto commuting, and subsequent auto-based grocery trips chained into those commutes; or, by encouraging the use of rail for the grocery trip itself. In the most recent Nationwide Household Transportation Survey, the category "grocery/hardware/clothes shopping" was the most common trip purpose, exceeding even commute trips in frequency (NHTS, 2009). Grocery trips may be among the most routine because food is a basic necessity, and may therefore be relatively easily to remember and report accurately.

I constructed a measure of auto-based grocery trips per week using answers to a question about the timing and mode of the last three grocery trips (see Appendix, survey question 9), dividing the weeks elapsed since the longest-ago reported grocery trip by the number of those trips that were conducted via auto. The variable was constructed only for the 878 respondents (77 percent of the pool) who reported full information on at least two grocery trips. Auto occupancy was not collected for non-work trips, so "auto" is defined as any auto trip including carpools. The variable is continuous, ranging from zero (in about five percent of cases) to as high as 10.5 trips per week, with a mean of 2.07 trips per week.

I estimated regressions using ordinary least squares. In the first model (Table 6, column 1), for each additional mile farther from a rail station there is an additional 0.51 auto-based grocery trips per week—an increase of about 30 percent of the median value of 1.61. New, nearby housing has 0.73 fewer auto grocery trips per week, and older nearby housing 0.39 fewer, before controlling for other factors. In the second grocery trip frequency model (Table 6, column 2), the significance of being within walking distance of rail disappears. Notably, however, the continuous distance-to-rail variable remains statistically significant, with an additional 0.32 trips per week for each mile further from a station. I return to this finding below. Each additional grocery store within a quarter mile of home is associated with a reduction of 0.12 trips per week. While one might expect to find *more* auto-based grocery trips when the grocery store is closer by, this result implies instead a shift to other modes. Parking has a particularly large relationship with auto-based grocery trips, with 0.63 fewer grocery auto trips per week for households living in housing units with low on- and off-street parking. Housing characteristics and small scale spatial variables are not significant. There are two apparently anomalous results: the number of bus stops within a mile is associated with *more* auto-based grocery trips, although this effect declines once demographic characteristics are controlled. It could be that part-time workers live in places with better local bus service and have more free time for multiple grocery trips. The second anomalous result is that distance from the Manhattan CB, is associated with fewer grocery trips via auto, rather than more, as might have been expected. It is possible that there are more but also shorter auto trips in places that have high bus accessibility and are nearer to Manhattan. Trip frequency and distance cannot be distinguished with these survey data.

[Table 6 about here]

Demographic and residential location criteria variables are added next (Table 6, column 3). The coefficients on the housing and spatial variables decline in magnitude, but not very much. The number of bus stops is no longer statistically significant. The effect associated with low on- and off-street parking availability remains large though somewhat less statistically significant, at 0.47 fewer grocery trips per week. Few other variables are significant in this model, other than the continuous distance to rail and the number of nearby grocery stores. Worker status is associated with fewer trips to the grocery store, which could be caused by time scarcity relative to non-workers. Of all of the stated residential choice criteria, only seeking "good schools" is associated with grocery store trip frequency.

When restricting the sample to houses near rail stations, the continuous distance to rail variable is no longer significantly associated with grocery trips (Table 6, model 4). Distance to rail apparently distinguishes farther-away households from each other. Perhaps some unobserved factor such as walking or biking access to grocery stores varies in that spatial range, farther from rail stations. The interaction of on- and off-street parking, and the number of grocery stores within a quarter mile, both remain significant, and in the case of grocery store counts, the estimate is significantly higher, increasing from 0.12 to 0.17 fewer grocery auto trips per week. The housing and spatial variables are no longer significant in this subset of households, partly because there is less spatial variation within walking distance of rail stations.

Finally, when vehicles per adult is added as an endogenous explanatory variable (Table 6, model 5), each additional vehicle per adult in the household is associated with an additional 0.4 auto-based grocery trips per week, and the independent influence of parking when both auto ownership and demographics are controlled declines to 0.45 fewer trips per week but remains statistically significant. In contrast to the auto commute models, this result implies that on- and off-street parking availability do affect auto-based grocery trips even for people with high auto ownership.

It is notable that only the combination of on-street and off-street parking scarcity is significant in grocery auto trip frequency, and not either parking on-street or off-street by themselves. This is intuitive. For non-work trips requiring goods carrying, such as grocery trips, the auto is doubly attractive and barriers to use of other modes will be higher.

Summary of analysis results

Some common themes emerge from these statistically controlled models of auto ownership, auto commuting, and auto-based grocery trip frequency. First, rail access is not independently correlated with auto ownership and use when controlling for other factors. This could be because rail tends to substitute for alternative modes rather than auto use. There is some evidence from the regressions restricted to households within walking distance that rail access in combination with low parking supply can reduce auto ownership.

Second, off-street parking, as well as the combination of on- and off-street parking supply, are highly correlated with auto ownership, commuting, and grocery trips—more consistently so than any of the other housing unit or spatial measures. The models restricted to near-station housing units are particularly important because in those models on-street parking data are available for almost all households. The measured correlations among near-station households are most different in the case of auto commuting, where the interaction of scarce on-street and off-street parking is most significantly associated with lower auto commuting rather than the independent effect of off-street parking scarcity found to be significant in the full sample (Table 5, columns 2 and 4).

Third, rental and smaller housing is strongly correlated with lower auto ownership, though not with commuting or with the frequency of auto-based grocery shopping. This could be partly due to households with fewer assets, including cars, choosing smaller and rental units.

Fourth, of the built environment variables, small scale measures are correlated with auto ownership while subregional measures are more correlated with auto commuting and grocery trips. This is consistent with previous literature that has emphasized the importance of larger scale context, and it suggests that isolated developments near rail stops serving low density areas are unlikely to have substantially lower auto use.

Finally, and unsurprisingly, it appears on- and off-street parking supply affects auto commuting primarily by reducing auto ownership, although its effect remains large and significant for grocery trips even when auto ownership is included as an endogenous explanatory variable (see column 5 in both Tables 5 and 6).

Conclusions

Permitting higher density development near rail stations may reduce regional congestion and pollution, and slow the growth in greenhouse gas emissions, but if so, those benefits don't depend primarily on station proximity. Other typically unobserved or neglected factors may be more important. This study provides some of the explicit empirical evidence that what matters about TOD is not the T (transit)—or at least not the R (rail)—but everything else, especially the parking availability, the characteristics of the housing units themselves, and bus service. This result is all the more remarkable given that rail is a particularly important mode of commuting and access in northern New Jersey where most of the housing units in this dataset are found.

The effects of non-rail factors could be large when looked at cumulatively. For example, the per-adult auto ownership of a rental apartment with less than one parking space per adult and with lower-than-median on-street parking supply is 60 percent lower than that for an owned single family home with ample off-street parking in the same station area (0.19 + 0.16 + 0.08 + 0.16) (Table 4).

Policy implications

Sustainable development efforts should be broadened beyond rail station areas. Denser housing development coupled with good management of automobile parking could have benefits in many contexts. Auto use and ownership may not be affected very much by changes in any single alternative mode, such as rail. Transit-oriented development often emphasizes rail investments and increasing transit ridership, but from the regional and global perspectives, what matters more is reducing auto use. Developing near rail stations may be an easier case to make to the public, but such (unintentional) deception may not serve long-term sustainability interests if it substantially reduces the scope of sustainable planning efforts.

We are fortunate if access to rail is not an overridingly important factor in reducing auto use. If so, there is merit in developing dense housing anywhere, not just in the fraction of available land near rail stations. Reducing parking supply is cheaper than investing in rail. So is providing more bus service, at least in terms of capital costs and when ridership is significant enough.

Not all of the significant factors in this analysis are susceptible to policy influence. For example, distance to the CBD and subregional employment density are significant predictors of auto commuting that do not imply much about localized development policies, although it does suggest the substantial benefits of developing densely near existing urban cores regardless of rail station access. But the policy potential is particularly high for on- and off-street parking. Public agencies are already heavily involved both in regulating minimum amounts of off-street parking and in providing and regulating on-street parking. New development could be required to have less off-street parking while on-street parking could be priced, or otherwise managed and permitted, to control the spillover effect of the reduced off-street requirements (Shoup 2005). On-street parking policies seem likely to matter more and more because future population growth in the US may well be concentrated in densifying cities, and on-street parking may become scarce. In this context on- and off-street parking policies are likely to become an important constraint to further densification.

The local parking problems and traffic congestion associated with transit-oriented housing development are a different set of concerns entirely from the regional and global impacts of such development, which have been the focus of this analysis. Local and regional impacts could work in opposite directions. There are several mechanisms by which reductions in auto use and ownership could occur in response to parking supply, housing size and tenure, and other factors. For example, on- and off-street parking scarcity could cause greater local auto congestion, due to more cruising for parking, that might in turn dissuade auto use and ownership on a per capita basis. Positive regional and global effects may result from negative local impacts if those local impacts quash more driving.

Barriers to housing development near transit may be similar to barriers to housing development everywhere, though areas near transit may be among the most likely to receive proposals for dense housing developments. The larger question is how to alter municipal permitting incentives more widely. For example, when off-street parking is free and required, it is often still grossly underused (e.g., Willson 1995). It is a much harder problem to address the local impacts and political opposition that are likely to be engendered by a more ubiquitous relaxation of existing development regulations. But that is the problem that may need more urgent attention, attention that in many metropolitan areas is being focused on developing housing on the relatively limited number of sites available near rail stations.

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FIGURE 1: Map of stations used to construct sample

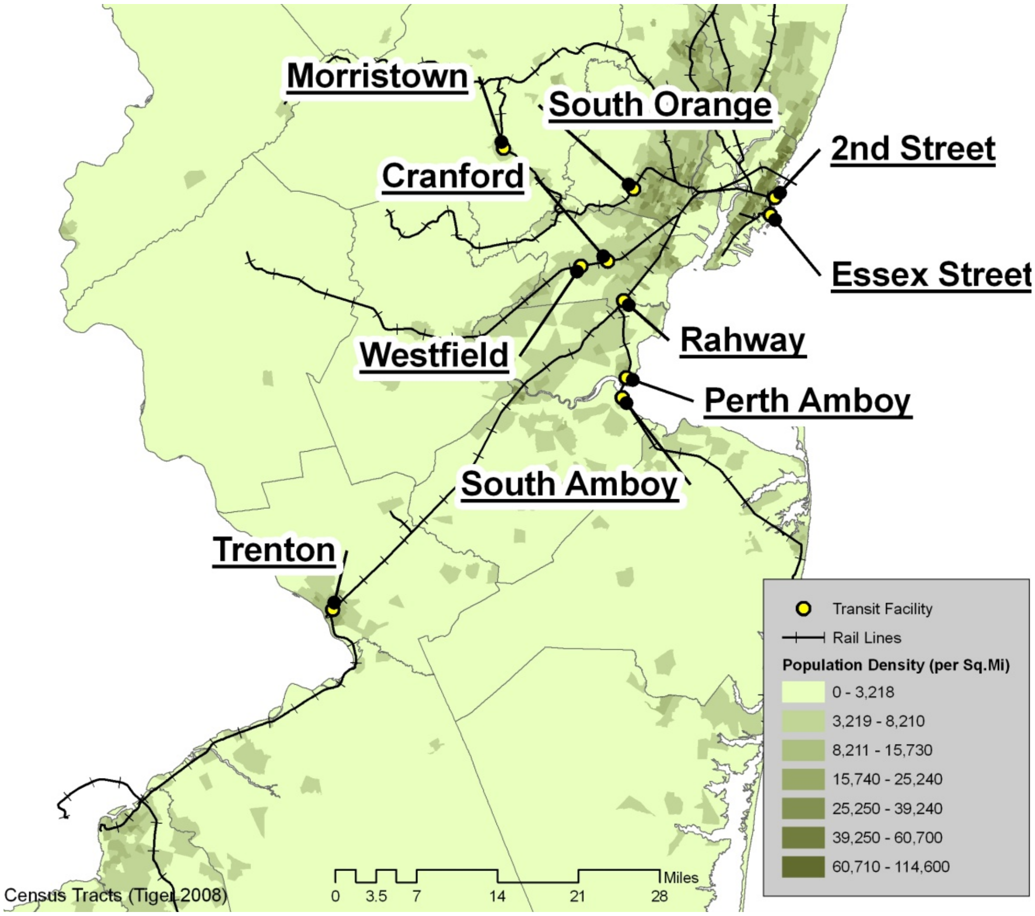

Figure 2: Household income ($10,000s) by stratum

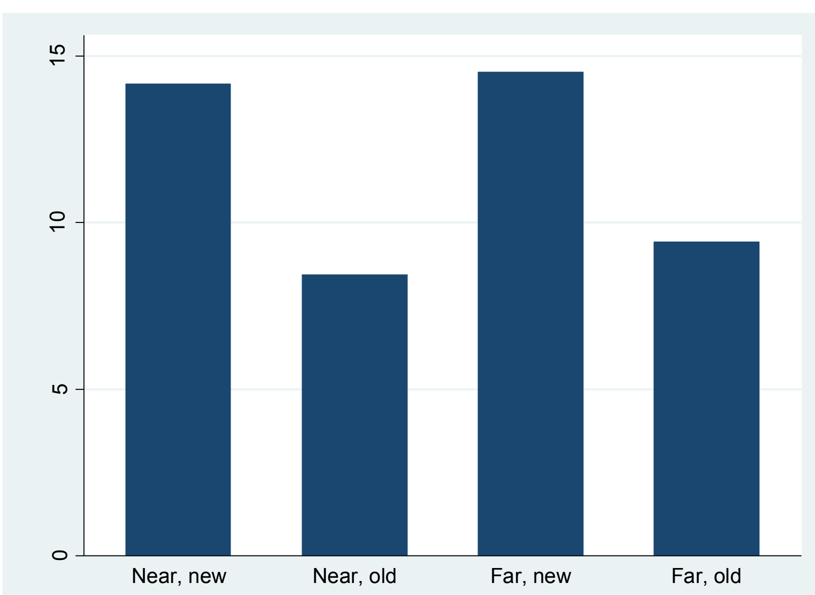

TABLE 1: Summary of dependent variables

Variable	Description	Obs	Mean	Std. Dev.	Min	Max
drail_mi	Distance to nearest rail station in miles	1,143	0.63	0.60	0.03	3.38
strnearnew	Housing 7 years old or newer, within 0.4 road mi of rail station	1,143	0.16	0.37	0	1
strnearold	Housing > 7 years old, within 0.4 road mi of rail station	1,143	0.33	0.47	0	1
strfarold	Housing > 7 years old, farther than 0.4 road mi of rail station	1,143	0.38	0.49	0	1
offparksca	Less than one off-street parking space per adult in household	1,089	0.34	0.47	0	1
ovsprdqmi	Overnight spaces (100s) per road mile within 1/4 mi of home	532	1.67	0.67	0.42	3.02
loo_ovrdq	Low on- & off-street parking (below-median ovsprdqmi & offparksca=1)	508	0.15	0.36	0	1
onstpark_z	On-street parking not observed	1,143	0.53	0.50	0	1
duptrip	Duplex or triplex	1,143	0.08	0.27	0	1
rowtown	Rowhouse or townhouse	1,143	0.08	0.27	0	1
aptcond	Apartment or condominium	1,143	0.51	0.50	0	1
otherhome	Other housing unit type	1,143	0.01	0.08	0	1
misshome	Missing housing unit information	1,143	0.01	0.08	0	1
rental	Rental unit	1,143	0.37	0.48	0	1
nomort	Home owned without mortgage	1,143	0.13	0.34	0	1
tenure_unk	Unknown unit tenure (owned or rented)	1,143	0.02	0.15	0	1
popdensemi	Population per sq mi (000s) in Census blocks within 1/8 mi of home (Census 2000)	1,133	12.59	12.20	0.13	87.58
empdenshmi	Jobs per sq mi (000s) in Census blocks within 1/2 mi of home (LEHD 2008)	1,143	8.51	14.74	0.00	89.55
retdenshmi	Retail jobs per sq mi (000s) in Census blocks within 1/2 mi of home (LEHD 2008)	1,143	0.46	0.50	0.00	4.78
bstops_1mi	Number of bus stops within 1 mi of home	1,143	103.68	118.67	0.00	622.00
eden_pum	Jobs per sq mi (000s) in home PUMA	1,143	4.15	5.53	0.40	19.63
bstden_pum	Bus stops per sq mi (10s) in home PUMA	1,143	3.76	5.96	0.31	23.67
CBDnetdist	Road distance from home to CBD (mi)	1,143	21.16	12.06	2.50	58.14
income	Household income ($10,000s, coded at category midpoints)	1,031	11.62	8.44	0.50	32.50
income_z	Household income not reported	1,143	0.10	0.30	0.00	1.00
hhsize_best	Household size	1,141	2.28	1.29	1.00	9.00
kids	Indicator variable for presence of children	1,131	0.24	0.43	0.00	1.00
par1	Indicator variable for single-parent household	1,131	0.03	0.17	0.00	1.00
hispanic	Hispanic status	1,143	0.14	0.34	0.00	1.00
black	African American	1,143	0.13	0.34	0.00	1.00
asian	Asian	1,143	0.06	0.24	0.00	1.00
nativam	Native American	1,143	0.01	0.10	0.00	1.00
race_unknown	Race not reported	1,143	0.04	0.19	0.00	1.00
worker	Respondent worked outside of the home last week	1,143	0.71	0.45	0.00	1.00
parttime	Worker worked part-time last week	1,143	0.07	0.26	0.00	1.00
management	Worker in management occupation	1,143	0.12	0.33	0.00	1.00
financial	Worker in financial occupation	1,143	0.08	0.27	0.00	1.00
sales	Worker in sales occupation	1,143	0.06	0.23	0.00	1.00
clerical	Worker in clerical occupation	1,143	0.04	0.20	0.00	1.00
craftsman	Worker in craftsman occupation	1,143	0.02	0.15	0.00	1.00
laborer	Worker in laborer occupation	1,143	0.02	0.15	0.00	1.00
service	Worker in service occupation	1,143	0.05	0.21	0.00	1.00
unkocc	Worker in unknown occupation (not reported)	1,143	0.02	0.14	0.00	1.00
retired	Respondent is retired from work	1,143	0.17	0.38	0.00	1.00
r_friends	Chose neighborhood based on access to friends/family	1,143	0.31	0.46	0.00	1.00
r_leisure	Chose neighborhood based on access to leisure opportunities	1,143	0.11	0.31	0.00	1.00
r_job	Chose neighborhood based on access to job	1,143	0.46	0.50	0.00	1.00
r_transit	Chose neighborhood based on access to transit	1,143	0.42	0.49	0.00	1.00
r_schools	Chose neighborhood based on access to childrens schools	1,143	0.16	0.37	0.00	1.00
r_pubserv	Chose neighborhood based on quality of public services	1,143	0.02	0.15	0.00	1.00
r_design	Chose neighborhood based on design	1,143	0.28	0.45	0.00	1.00
r_distsch	Chose neighborhood based on distance to school	1,143	0.05	0.23	0.00	1.00
r_distshop	Chose neighborhood based on distance to shops	1,143	0.18	0.39	0.00	1.00
r_disthwy	Chose neighborhood based on distance to highway	1,143	0.09	0.29	0.00	1.00

Table 2: Auto ownership and use by age of housing and distance to rail (mean values)

Stratum	Vehicles per household	Vehicles per adult in household	Commute via auto (indicator variable)	Grocery trips via auto, per week
New housing near rail	1.14**	0.73*	0.36**	1.47**
Older housing near rail	1.40**	0.81*	0.59	1.84**
Older housing farther from rail	1.77	0.86*	0.67	2.44
New housing farther from rail	1.67	0.96	0.63	2.45

* = statistically significant difference from new housing farther from rail at the 95 percent level.

** = value is significantly different from the value for the category below it, at the 95 percent level.

Notes: “New housing” is constructed seven or fewer years prior. “Near rail” is within 0.4 network miles of a rail station. In “Commute via auto,” auto is defined as a singly-occupied vehicle.

Table 3: Housing, parking and spatial characteristics by age of housing and distance to rail (mean values)

Stratum	(1) Rental unit	(2) Apartment/ condo/ townhouse/ rowhouse	(3) Less than one off-street parking space per adult	(4) On-street parking per road mile	(5) Low on- and off-street parking	(6) Population density (000s per sq mi)	(7) Bus stops within one-mile radius
New housing near rail	0.57**	0.98**	0.47*	193**	0.12	13,200*	152**
Older housing near rail	0.48**	0.62**	0.39**	152	0.17	12,800*	93
Older housing farther from rail	0.29**	0.37**	0.30**	[183]*	[0.07]	13,400*	101*
New housing farther from rail	0.16	0.71	0.19	[149]	[0.25]	7,810	79
Number of observations	1,116	1,135	1,089	532	508	1,143	1,143

* = statistically significant difference from new housing farther from rail at the 95 percent level.

** = value is also significantly different from the value for the category below it, at the 95 percent level.

Notes: “New” housing is 7 or fewer years old at the time of the survey. “Near” rail is defined as 0.4 network miles. Figures in brackets in columns 5 and 6 denote small subsample sizes because on-street parking was observed primarily for housing units within walking distance of rail.

vehicles per adult in household
OLS regressions

	-1		-2		-3		-4	
	All households, Age and rail distance only		All households, add housing, parking, and spatial variables		households, add demographic and preference variables		Near-station households, Same variables as Model 2	
Distance to rail (miles)	0.091	***	-0.0034		-0.018		0.16	
New housing near rail	-0.18	***	0.01		0.045		0.041	
Older housing near rail	-0.11	**	-0.029		0.0017			
Older housing farther from rail	-0.14	***	-0.048		-0.019			
Scarce off-street parking			-0.16	***	-0.11	***	-0.12	**
On-street overnight parking spaces			0.011		-0.0077		0.011	
Scarce on- and off-street parking			-0.13	**	-0.11	*	-0.24	***
Apt/condo/row/townhouse			-0.065	*	-0.13	***	-0.027	
Unit type unknown			-0.35		-0.4	*	-0.23	
Rental unit			-0.13	***	-0.1	***	-0.15	***
Job density, 1/2-mi (000s)			-0.0023		-0.003	**	-0.0013	
Bus stops, 1-mi radius			-0.00079	***	-0.00065	**	-0.00041	
Household income ($10,000s)					0.006	***		
Owned home without mortage					0.074	*		
Household size					-0.065	***		
Single-parent household					0.29	***		
Hispanic					-0.075	**		
African-American					-0.07	*		
Service occupation					0.16	***		
Nhood choice: Friends					0.055	**		
Nhood choice: Leisure					0.1	**		
Nhood choice: Access to job					0.051	*		
Nhood choice: Near transit					-0.098	***		
Nhood choice: Public services					-0.2	**		
Nhood choice: Looks/design					0.081	***		
Nhood choice: Near school					0.13	**		
Nhood choice: Near highway					0.11	***		
Constant	0.9	***	1.11	***	1.03	***	1.23	***
Observations	1118		1071		1063		525	
* p<0.10, ** p<0.05, *** p<0.01								

Included, not shown, insignificant at 0.10: Duplex/triplex, unit type missing, local population density, local retail job density, distance to CBD, bus stop density in subregion, job density in subregion, tenure unknown; household income missing, children in household, Asian-American, Native American, race unknown, management occupation, financial occupation, sales occupation, clerical occupation, craft occupation, labor occupation, occupation unknown, full-time worker, part-time worker, retired, nhood choice: school district, nhood choice: near shops/services, nhood choice: house characteristics, nhood choice: other.

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Probability of commuting by singly-occupied vehicle
Logit model; odds ratios presented
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	-1		-2		-3		-4		-5	
	All households, Age and rail distance only		All households, add housing, parking, and spatial variables		All households, add demographic and preference variables		Near-station households, Same variables as Model 2		All households, add vehicles per adult to Model 3	
Distance to rail (mi)	1.74	***	1.34		1.2		2.83		1.22	
New housing near rail	0.43	***	1		1		0.61	*	1.02	
Older housing near rail	1.06		1.68	*	1.41				1.83	*
Older housing farther from rail	1		1.79	**	1.61				1.93	**
Scarce off-street parking			0.63	**	0.57	**	0.85		0.83	
On-street overnight parking spaces			1.3		1.1		1.13		1.51	
Scarce on- and off-street parking			0.6		0.62		0.4	**	0.75	
Tenure unknown			5.71	*	6.6	*	2.89		7.64	**
Population density, 1/8-mi (000s)			0.98	**	0.99		0.97	**	0.98	
Job density, 1/2-mi (000s)			0.99	*	0.99	*	0.99		0.99	
Bus stop density, subregion (10s)			0.95	*	0.95	**	0.97		0.97	
Distance to downtown (mi)			1.02	**	1.02		1.03		1.03	**
Household income > $25k					2.43	*				
Race unknown					0.35	*				
Labor occupation					3.12	**				
Nhood choice: Leisure					3.26	***				
Nhood choice: Access to job					2.06	***				
Nhood choice: Near transit					0.39	***				
Nhood choice: School district					1.75	**				
Nhood choice: Near school					2.7	**				
Nhood choice: Near highway					1.96	**				
Nhood choice: Other					1.68	*				
Vehicles per adult in HH									7.59	***
Observations	810		785		782		400		773	
Exponentiated coefficients										
* p<0.10, ** p<0.05, *** p<0.01										

Included, statistically insignificant, not shown: On-street parking not observed, Duplex/triplex, Apt/condo/row/townhouse, Mobile home, other home, Unit type unknown, Rental unit, Retail job density , Household income , HH income missing, Owned home without mortage, Household size, Children in household, Single-parent household, Hispanic, African-American, Asian-American, Native American, Management occupation, Financial occupation, Sales occupation, Clerical occupation, Craft occupation, Service occupation, Occupation unknown, Part-time worker, Nhood choice: Friends, Nhood choice: Public services, Nhood choice: Looks/design, Nhood choice: Near shops/services, Nhood choice: House important

Grocery auto trip frequency (per week)
OLS regressions

	-1		-2		-3		-4		-5	
	All households, Age and rail distance only		All households, add housing, parking, and spatial variables		All households, add demographic and preference		Near-station households, Same variables as Model 2		All households, add vehicles per adult to Model 3	
Distance to rail (miles)	0.51	***	0.33	***	0.28	**	0.6		0.33	***
New housing near rail	-0.73	***	-0.011		-0.065		0.053		-0.059	
Older housing near rail	-0.39	**	-0.099		-0.25				-0.081	
Older housing farther from rail	-0.22		-0.14		-0.22				-0.13	
Scarce off-street parking			0.2		0.13		0.16		0.22	
On-street overnight parking spaces			-0.14		-0.16		-0.094		-0.14	
Scarce on- and off-street parking			-0.57	**	-0.48	*	-0.6	**	-0.45	*
On-street parking not observed			0.08		0.04		-0.14		0.11	
Grocery stores, 1/4-mi			-0.098	***	-0.11	***	-0.14	***	-0.097	***
Bus stops, 1-mi radius			0.0023	**	0.0014		0.00009		0.0026	**
Job density, subregion (000s)			-0.07	**	-0.045		0.014		-0.068	**
Bus stop density, subregion (10s)			-0.077	***	-0.057	***	-0.068		-0.074	***
Distance to downtown (mi)			-0.034	***	-0.03	***	-0.013		-0.035	***
Household income ($10,000s)					-0.013	*				
Full-time worker					-0.41	**				
Nhood choice: School district					-0.31	*				
Vehicles per adult in HH									0.4	***
Constant	2.09	***	3.42	***	3.99	***	2.84	***	2.98	***
Observations	878		855		851		428		843	
* p<0.10, ** p<0.05, *** p<0.01										

Included, statistically insignificant, not shown: Duplex/triplex, Apt/condo/row/townhouse, Mobile home, other home, Unit type unknown, Rental unit, Tenure unknown, Population density, 1/8-mi (000s), Job density, 1/2-mi (000s), Retail job density, 1/2-mi (000s), HH income missing, Owned home without mortage, Household size, Children in household, Single-parent household, Hispanic, African-American, Asian-American, Native American, Race unknown, Management occupation, Financial occupation, Sales occupation, Clerical occupation, Craft occupation, Labor occupation, Service occupation, Occupation unknown, Part-time worker, Retired, Nhood choice: Friends, Nhood choice: Leisure, Nhood choice: Access to job, Nhood choice: Near transit, Nhood choice: Public services, Nhood choice: Looks/design, Nhood choice: Near school, Nhood choice: Near shops/services, Nhood choice: Near highway, Nhood choice: House impt, Nhood choice: Other