Transit Oriented Development's Ridership Bonus: A Product of Self-Selection and Public Policies

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Abstract

Transit oriented development is shown to produce an appreciable ridership bonus in California. This is partly due to residential self-selection – i.e., a life-style preference for transit-oriented living – as well as factors like employer-based policies that reduce free parking and automobile subsidies. Half-mile catchments of station areas appear to be indifference zones in the sense that residents generally ride transit regardless of local urban design attributes. Out-of-neighborhood attributes, like job accessibility and street connectivity at the destination, on the other hand, have a significant bearing on transit usage among station-area residents. The presence of self-selection, shown using nested logit modeling, underscores the importance of removing barriers to residential mobility so that households are able to sort themselves, via the marketplace, to locations well-served by transit. Market-responsive zoning, flexible residential parking policies, location efficient mortgages, and adaptive re-use of parking lots are also promising tools for expanding the supply of transit-based housing.

1. Introduction

Transit-oriented development (TOD) has gained currency in the United States as a sustainable form of urbanism. By siting housing, workplaces, and other urban activities within an easy walk of rail stations, proponents maintain that transit and walk trips will substitute for what otherwise would be private-car travel (Cervero et al., 2004). TOD finds broad ideological appeal in part because the average citizen understands that if there is a logical place to target compact, mixed-use development, it is around train stations.

To some, "TOD" and "United States" in the same sentence is an oxymoron. After all, the U.S. is the world's most car-dependent society, prodigious in its consumption of cars and the fossil fuels that propel them, and in the emission of pollutants and greenhouse gases that come out their tailpipes. TOD aims to reverse course by creating a built form – mixed land uses configured around rail stops, interlaced by pedestrian amenities – that is conducive to transit riding. More than 100 TODs were identified in the U.S. in a recent survey of local transit officials, ranging from moderate-size commercial projects adjacent to bus transfer facilities to veritable mini-cities, like Ballston in Arlington, Virginia and Atlanta's Lindbergh station, built above subway portals (Cervero et al., 2004). Not all of America's TODs are transit-friendly, for reasons like the prevalence of free parking and the absence of good sidewalk connections, thus in some instances, the term "transit adjacent development" (TAD) is a more accurate descriptor.

This paper probes the ridership impacts of TOD drawing upon experiences in California -- the American state with not only the most inhabitants but also where more miles of urban rail-track have been laid over the past two decades than any other. Furthermore, severe shortages of affordable housing have prompted a flurry of building activity around many of California's 300-plus urban rail stations. Between 1998 and 2002, 13,500 apartment and condominium units were built within one-half mile of urban stations in Southern California and the San Francisco Bay Area. In some instances, apartments and condominiums have been constructed on what only a few years ago were surface park-and-ride lots.

Following a review of the literature, this paper measures the ridership bonus among those living near California rail stations vis-à-vis those who reside beyond a walkable distance of stations. Choice models are estimated that account for factors influencing ridership levels among TOD residents. Also, factors that explain the likelihood of TOD residents walking or cycling to nearby stations are identified. An analysis is also carried out that examines changes in accessibility and other performance measures before and after residents moved to TODs. This is followed by an analysis that predicts ridership levels not only for residents of TODs but also region-wide using data from the San Francisco Bay Area. Nested logit models are estimated that account for the influences of self selection by predicting ridership as a derivative of residential location. Using conditional probabilities, the degree to which lifestyle preferences influence mode choice is examined. The paper concludes with discussions on the broader policy implications of TOD residency and self selection.

2. Transit-Oriented Residences and Ridership in America

If there is any single aspect of TOD that all sides agree is beneficial to society as a whole, it is increased ridership (Calthorpe, 1993; Bernick and Cervero, 1997). TOD is poised to relieve traffic congestion, improve air quality, cut down on tailpipe emissions, and increase pedestrian safety in transit-served neighborhoods by coaxing travelers out of cars and into trains and buses. However, such benefits accrue only if TODs result in people who formerly drove alone now switch to transit. While some critics charge that past rail investments in the U.S. have largely lured former bus riders to rail, experiences show that TOD can attract significant shares of former motorists. A California study found that among those who drove to work when they lived away from transit, 52.3 percent switched to transit commuting upon moving within ½ mile walking distance of a rail station (Cervero, 1993).

Past studies that have sought to gauge the "ridership bonus" of TODs have compared transit modal shares among those living within a walkable distance of stations versus those who live farther away. Surveys from the early 1990s of residents of multi-family complexes near suburban rail stations in the San Francisco region showed upwards of 45 percent took rail-transit to work, much higher than the regional average of 9 percent (Cervero, 1994). Car availability and parking prices had a huge bearing on ridership rates. Station-area residents from zero-car households were 14 times more likely to rail-commute than those from three-car households. And 42 percent of station-area residents who paid for parking at their workplaces commuted by rail compared to just 4.5 percent who received free parking.

Even higher transit capture rates have been recorded among those living near rail stops in the Washington, D.C. metropolitan area (JHK and Associates, 1987, 1989). Surveys from the late 1980s showed that the shares of work trips taken by rail ranged from 18 percent to 63 percent, with the rates among residents of Arlington County, Virginia heading to jobs in the District of Columbia. More recent surveys of those living along the highly urbanized four-mile long, half-mile wide Rosslyn-Ballston Metrorail corridor reveal that 39 percent use transit to get to work and 10 percent walk or bike, rates that are three times higher for Arlington County as a whole (Cervero, et al. 2004).

While the chief environmental benefit of TOD comes from coaxing motorist over to mass transit, a secondary benefit is the inducement of walk and bicycle access trips. Larger shares of rail trips accessed by foot and bicycle can reduce the need for parking, improve air quality (particularly by eliminating cold starts), and promote physical activity. In the case of Arlington County, Virginia, 64 percent of rail patrons who live along the Rosslyn-Ballston corridor walk to stations. A study in California found that factors like sidewalk connectivity and mixed land uses significantly increased the likelihood of rail commuters accessing stations by foot or bicycle (Cervero, 2001).

Another important ridership dimension of TODs is their mixed-use attributes. Some land uses, like offices and residences, produce trips during peak hours when trains and buses are often full. Others, like entertainment complexes, restaurants, and retail shops, generate trips mainly during off-peak hours, helping to squeeze efficiencies in the deployment of costly rail services. When mixed-use TODs are aligned along linear corridors – like "pearls on a necklace" – they result in trip origins and destinations being evenly spread, producing efficient bi-directional flows. This has been the case in world-class transit metropolises like Stockholm, Copenhagen, and Curitiba, Brazil wherein mixed-use TODs have given rise to 55%-45% directional splits (Cervero, 1998). In contrast to many American settings where peak-period trains and buses are filled to the brim in one direction but nearly empty in the other, mixed and balanced land uses ensure mixed and balanced traffic flows. The Rosslyn-Ballston corridor shows this is the case

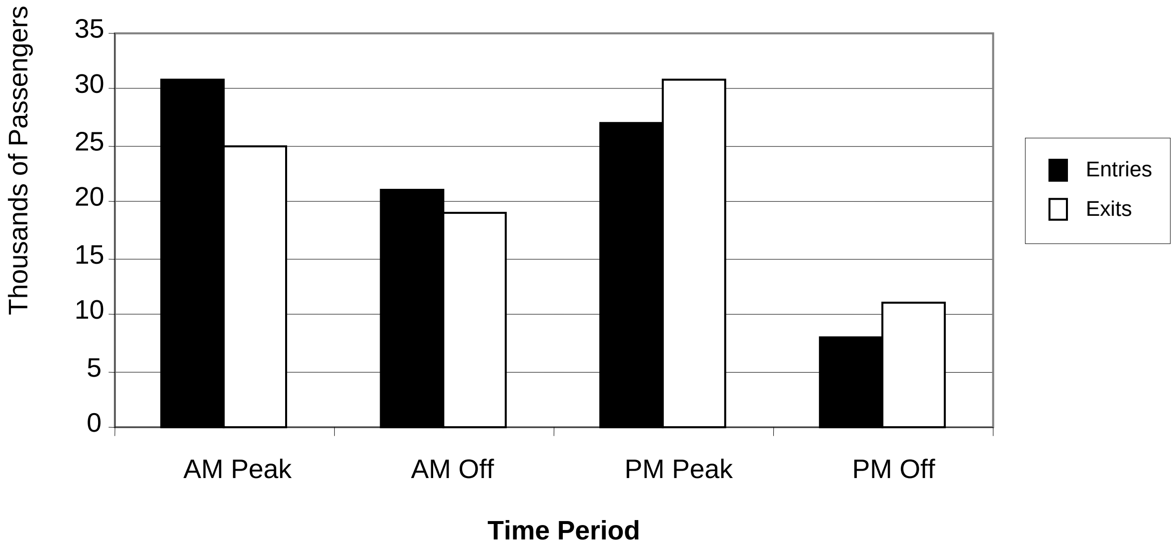

Figure 1. Metrorail Stations Entries and Exits by Time Period along the Rosslyn-Ballston Axis in Arlington County, Virginia

even in America. Figure 1 shows that counts of station entries and exits along this corridor were nearly equal during peak and off-peak hours. During rush hours, the corridor's Metrorail stations are both trip origins and destinations. The presence of so much retail-entertainment-hotel activities along the Rosslyn-Ballston axis has filled trains and buses during the midday and on weekends.

3. TOD Ridership and Public Policy

Why is it important to study the ridership impacts of TOD? The principal reason is that evidence can be useful in informing public policy. One application is the setting of credits against transportation impact fees, a significant form of financing urban infrastructure expansion in the United States whereby developers contribute to an escrow fund to help finance new roads and expansions. Los Angeles and Santa Clara County, California currently employ sliding-scale impact fees, adjusting charges downward for TODs. The Santa Clara County Congestion Management Agency recommends a 9 percent reduction in estimated trip generation levels when setting impact fees for new housing projects that lie within 2000 feet of a light rail or commuter rail station.

Research can also help inform policy initiatives like Location Efficient Mortgage (LEM) programs (Krizek, 2003)– an innovative scheme adopted in several U.S. cities that makes it easier to qualify for home purchases in settings well-served by transit – by shedding light on the commuting cost savings of transit-based housing. Studies suggest that in the San Francisco Bay Area, living in very low-density residential areas and receiving minimal transit services increases the average cost of owning and operating cars by around $8,000 per year (Holtzclaw et al., 2002). Residing in compact transit-served neighborhood can cut these costs in half, freeing up income for housing purchases. LEMs acknowledge this when qualifying buyers for mortgages. Lastly, research on TOD and ridership can be of value to long-range modeling whose outputs weigh heavily on how scarce transportation dollars are allocated in Transportation Improvement Programs (TIPs). Recent scenario testing in Sacramento, California using an integrated land-use and transportation model, for example, showed rail investments combined with TOD and road pricing was more cost-effective and environmentally benign than a ring-road scenario (Hunt et al., 2001).

4. TOD and Ridership in California

This section gauges the ridership bonus of TOD residency in California, followed by statistical modeling of factors influencing residents' mode choices and before-and-after comparisons of travel behavior. The analyses draw upon a database on travel and other attributes of nearly 1000 residents living in 26 housing projects within ½ mile of California urban rail stations who were surveyed in 2003 (Lund et al., 2004). The 26 surveyed housing projects were served by a variety of rail services: heavy rail (i.e., powered by a high-voltage third rail) in the San Francisco Bay Area and Los Angeles; light rail (i.e., powered by overhead electrical wires) in Los Angeles, San Diego, and Sacramento; and commuter rail (i.e., diesel-electric locomotion) serving the San Francisco-San Jose axis, northern San Diego County, and Los Angeles-Orange County.

Ridership Bonus of TOD

Based on one-day travel diaries completed by adult residents of the 26 surveyed TOD housing projects, the mean share of commute trips by transit was 27 percent. This figure was compared to those living in a "donut": an area between ½ and 3 miles of a

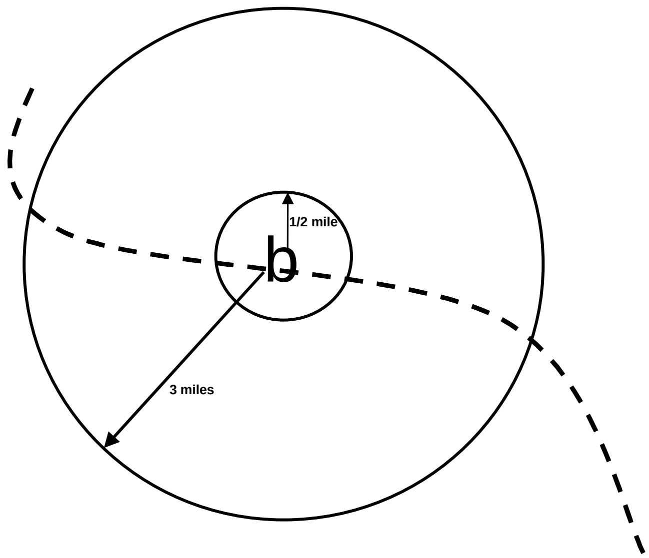

Figure 2. Schematic of TOD Residency (1/2 Mile Radius) and "Donut" (1/2 to 3 mile Radius)

station, as represented in Figure 2. The mean share of commute trips via transit among those residing in the donut was 7 percent. Thus, those living within ½ mile of a rail stop were around four times as likely to rail-commute as those living within a distance more oriented to bus access (i.e., ½ to 3 miles). And when compared to those living beyond 3 miles but within the same city as the housing projects under study, the differential in transit commute shares was six-fold.

Choice Model of TOD Residency

What factors explain the decision to ride transit among those living near California rail stations? To address this question, data on socio-demographic, neighborhood, and travel attributes of surveyed TOD residents in California, along with isochronic job-accessibility measures, were combined to estimate mode choice models. Table 1 presents best-fitting binomial logit models for predicting transit choice for journeys to work among surveyed residents.

Controlling for important utility factors that sway mode choice – notably comparative travel times by car versus transit, accessibility levels by auto, and the need to chain trip ends – Table 1 reveals that a number of policy-related variables had significant marginal influences on mode choice. Among the variables within the sphere of policy influence, workplace variables were generally most influential – particularly the

Table 1. Binomial Logit Models for Predicting Transit Choice for Work Trips among TOD Residents

	Coef.	Wald	Prob.
Travel Time and Patterns			
Comparative Times: [(travel time via highway network)/(travel time via transit network)]	3.180	9.70	.000
Chained trip (1=yes; 0=no)	-2.147	11.15	.000
Regional Accessibility			
Job Accessibility via Highways: No. of jobs (in 100,000s) that can be reached via highway network within 60 minutes peak travel time	-0.040	3.86	.032
Workplace Policies			
Flex-time (1=yes; 0=no)	4.194	54.66	.000
Free parking (1=yes; 0=no)	-2.370	22.12	.000
Employer helps with car expenses (1=yes; 0=no)	-3.618	19.17	.000
Neighborhood Design			
Connectivity levels at destination: proportion of intersections that are 4-way or more within 1 mile of workplace	4.137	16.81	.000
Socio-demographic and Attitudinal Controls			
Auto ownership levels: No. of motorized vehicles per household member 16 yrs. or older	-2.976	27.13	.000
Transit lifestyle preference: access to transit a top factor in choosing residential location (0-1)	1.471	10.42	.000
Constant	-1.994	5.55	.011
Summary Statistics			
No. Cases = 726			
Chi-Square (sig.) = 585.9 (.000)			
ρ^2 (McFadden) = .852			
Note: Wald Statistic equals t-statistic squared			

availability of flex-time (generally a transit inducement) and employer-provided free parking and car allowances (transit deterrents). The most influential single variable was the availability of flex-time at the workplace. Evidently, being able to flex one's work hours made transit riding easier, possibly because residents then enjoyed more latitude in choosing when to ride (e.g., avoiding the heart of the peak to ensure a seat). Another explanation might be that TOD residents with certain attributes not in the equation, like higher education, tend to both transit-commute and enjoy flex-time privileges. In contrast, neighborhood design factors, representing built-environment attributes within one-half mile of trip origins and destinations, had relatively limited influences once other variables were controlled. In fact, the only neighborhood-design variable that provided significant marginal explanatory power was the level of street connectivity at the destination (among several dozen variables representing densities, land-use mixes, and design features that were available for model entry). When exiting a station en route to work, having a walkable grid-street pattern with high connectivity matters to station-area residents when deciding whether to commute via transit.

The model results also say something about the influences of car ownership, attitudes, regional accessibility, and other travel attributes on mode choice. Consistent with expectations, having plentiful motorized vehicles in the household discourages transit commuting among station-area residents. The lifestyle desire to live in an area with good transit access, as revealed by an attitudinal question on factors influencing residential choice, increased transit commuting. This suggests that self-selection could weigh heavily in ridership choices among California's station-area residents, a topic addressed later in this paper. Also, the model shows that the more accessible jobs are within a 60-minute peak travel time over the highway network, the less likely station-area residents will take transit. Job accessibility over regional highway networks was a much stronger predictor of mode choice than job accessibility over regional transit networks. Clearly, residents living near California rail stations enjoy accessibility benefits, however only if transit provides mobility advantages over auto-highway travel; otherwise, residents will drive, even if they live within an easy walk of transit. One way to enhance job-accessibility via transit is to site more and more workplace destinations near transit, as done in much of Europe (Cervero, 1998). Clearly, TOD yields benefits only if multiple land-use activities – not just housing, but workplaces, retail shops, and educational facilities – are organized around transit stops.

It useful to note that although workplace practices strongly influence commute mode choices of among station-area residents, such practices are usually outside the sphere of influence of municipalities pursuing TOD. If employers opt not to pass on parking charges to their workers, local planners who wish to encourage more transit riding among station-area residents can do little about this. Planners can influence the densities and designs of neighborhoods around rail stations through zoning, however these and other land-use attributes of station areas did not enter the models as significant predictors.

Overall, the model results suggest local policy-makers have fewer levers available to influence transit riding among station-area residents than regional policy-makers. Local officials can control land uses around stations, however these variables had minimal explanatory power. Regional agencies, on the other hand, are in a position to introduce measures that encourage employers to promote transit (e.g., underwriting the cost of transit passes) and discourage car commuting (e.g., eliminating free parking) – both "workplace policy" variables were significant predictors. California has considerable precedence in this regard under the "Employer Commute Options" initiatives mandated by Federal and State clean-air legislation in the 1990s; today, such employer-based policies are largely voluntary.

When it comes to transit-based residences, the greatest ridership pay-off comes for intensifying station-area housing. While streetscape improvements, parking provisions, and other physical-design elements might influence the attractiveness of station-area housing among prospective tenants, such factors appear to exert minimal influences on whether station-area residents opt for transit or not. It is housing supplies, not station-area designs and parking levels, which are the strongest localized factors influencing ridership in neighborhoods abutting rail stations in California. This suggests the presence of an "indifference zone": for those living within a half-mile or so of a station, they will generally ride transit regardless of local urban design features. On the other hand, out-of-neighborhood attributes, like job accessibility and street connectivity at the destination, have a significant bearing on transit usage.

Sensitivity Test of Workplace Policies

For purposes of examining the sensitivity of transit choice to changes in workplace policy variables, a sensitivity test was conducted. This involved inputting values of variables inthe logit models (from Table 1) to estimate probabilities for the "typical" station-area resident, and then changing inputs for selected variables while holding values for all other variables constant.

Figure 3 plots the results. At a travel-time ratio where it takes 30 percent longer to go by transit than car during peak hours (i.e., 0.7), there is only a 5 percent chance that

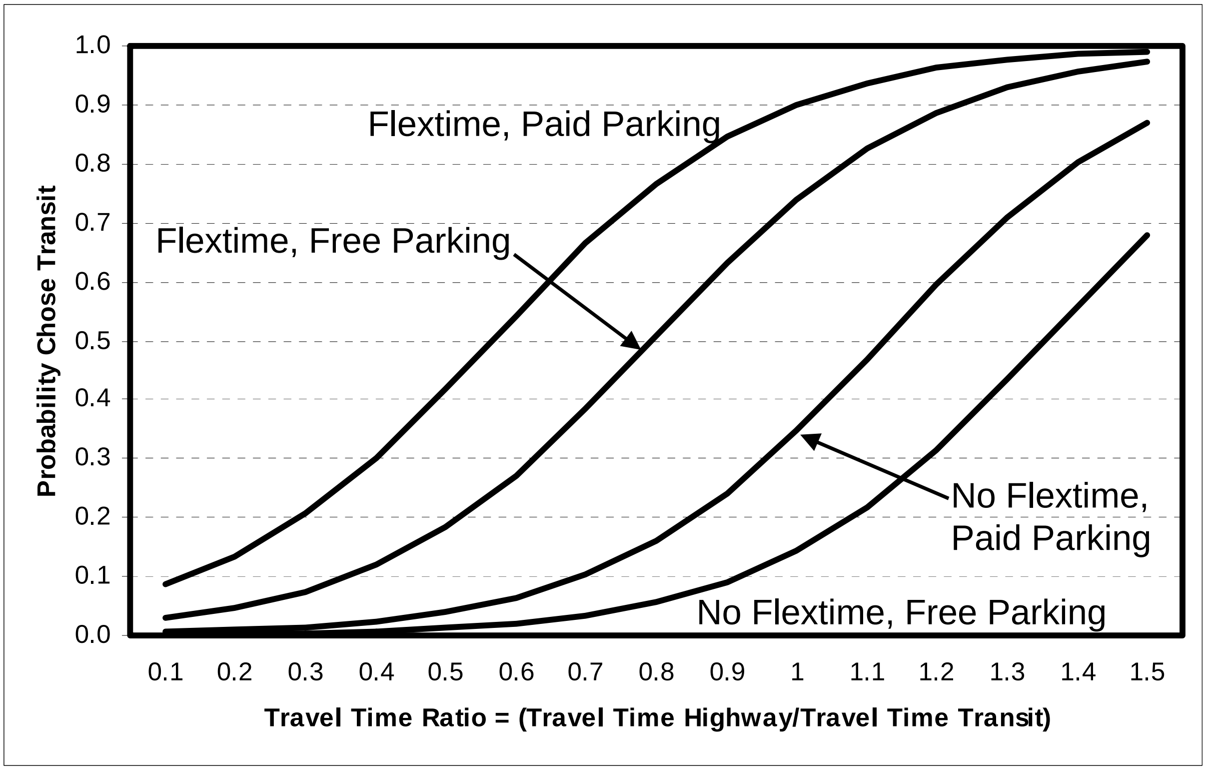

Figure 3. Sensitivity of Rail Commuting to Parking Prices, Availability of Flextime Work Schedules, and Travel Time Ratios

a station-area resident will take transit if parking is free and flex-time is not available. Charging for parking bumps the probability up to around 10 percent, all else being equal. Introducing flextime, but retaining free parking, raises the likelihood of transit commuting to 40 percent. And combining flex-time with paid parking increases the likelihood of transit riding up to nearly 70 percent.

As important as workplace policies is the relative speed advantages of transit. Figure 3 shows that when transit offers a 20 percent or more travel time savings relative to the car during peak hours, the likelihood that a station-area resident with flex-time will take transit to work is well over 90 percent. Combining paid parking at the workplace raises the probability to around 99 percent. Clearly, quality-of-transit services and workplace policies matter a lot to California's station-area residents.

Changes in Residences and Ridership

The survey of TOD residents in California compiled commuting data not only for their current locations but also their prior (i.e., non-TOD) residences. Surveyees were asked how they typically got to work from their previous residence. (Only individuals who did not live in a TOD and whose workplace addresses did not change before and after the move were included in the analysis). Commute distances and durations were estimated using address data on residences and workplaces for both past and current locations, enabling isochronic measures of job accessibility to be estimated for both locations. Trip origin-destination data also allowed daily commute Vehicle Miles Traveled (VMT) to be estimated, adjusted for mode (i.e., "mode-adjusted VMT"). This adjusted metric accounts for occupancy levels of motorized vehicles and whether new vehicle trips were added. If someone was in a 3-person carpool, that person'sVMT was divided by three to recognize that his or her individual contribution to travel consumption as one-third of the total. Also, VMT values for walking, bicycle, and transit were set to zero since these trips by these modes did not add new motorized vehicles to city streets.

Figure 4 summarizes the "before-and-after" findings for 226 survey respondents. TOD residency clearly enhanced accessibility while reducing motorized travel. Based on cumulative counts of jobs within 30 minutes travel time (P.M. peak over highway and transit networks), moving from a non-TOD to a TOD location increased job-accessibility, on average, by 6.5 percent. Mean commute times went down, in spite of the switch of many residents to transit modes, in part because of the reduced walk access time associated with TOD living. And because of mode shifts from driving to transit usage, the average mode-adjusted VMT plummeted some 42 percent once people moved to TODs. Lastly, the estimated average daily dollar outlays for getting to and from work fell largely because workers switched from private cars to public transit (based on comparing transit fares versus cost of car travel factoring trip distance by a mileage cost and accounting for parking expenses and tolls). From a societal perspective, these findings suggest both individuals and society at-large benefit from TOD: accessibility is materially improved and resource consumption (travel time, motorized travel) is reduced.

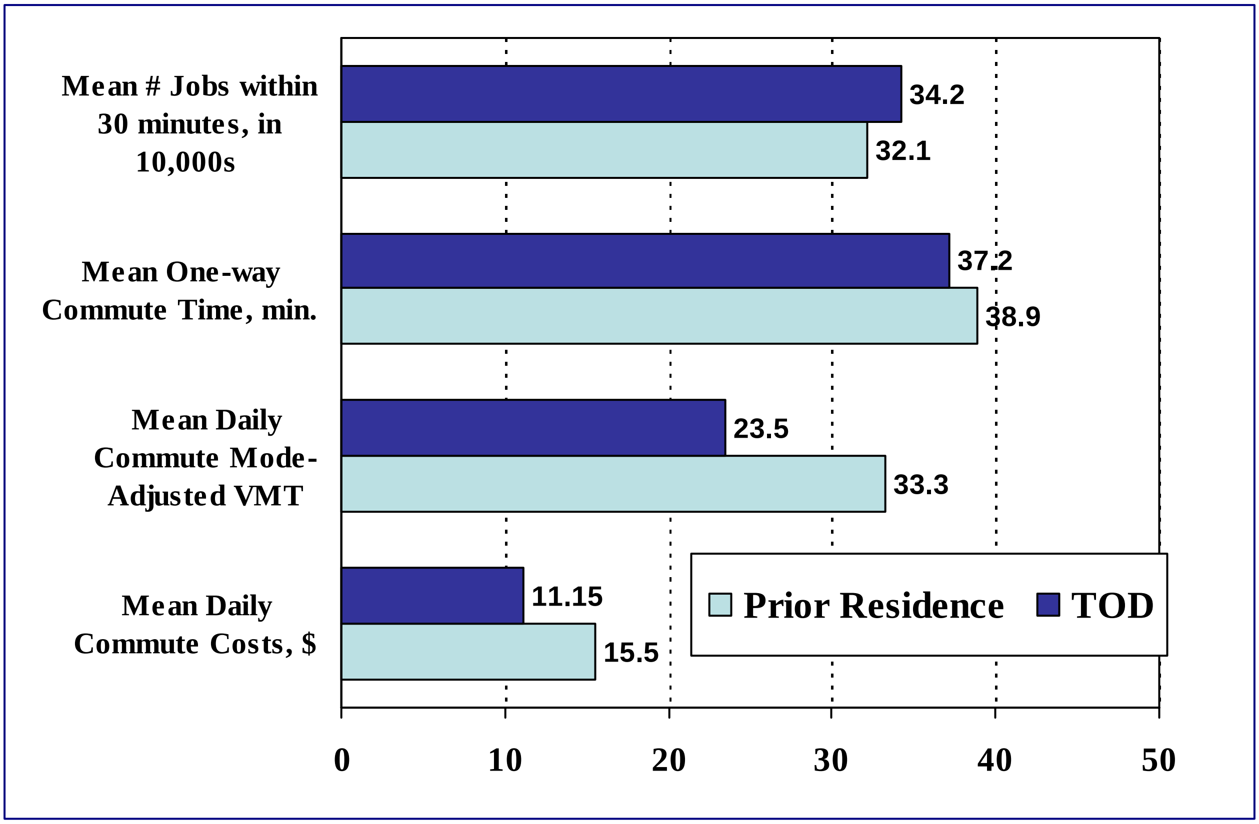

Figure 4. Mean Changes in Commute Accessibility, Mobility, and Affordability from Prior (Non-TOD) to TOD Residences

5. Non-Motorized Access to Rail Stations

Among Californians living near rail stops, what factors influenced how they reached stations? Given that the surveyed housing projects were within a half-mile of stations, an eminently walkable distance, reasonable shares of rail travelers might be expected to arrive by foot or bicycle. Indeed, over 85 percent of access trips were by non-motorized transport (NMT): predominantly walking, but also biking and other means (e.g., roller-blading). However, this also means that fully 15 percent opted for some form of motorized transit to get to fairly close-by stations.

A choice model was estimated to predict whether surveyed station-area residents accessed stations by NMT. Given the limited variation in access mode choice, a choice model with limited explanatory variables and power was expected. This was the case. Table 2 shows that high car ownership levels deterred walking/biking access. Transit

Table 2. Best-Fitting Binomial Logit Model for Predicting Non-Motorized Access to Rail Stations by Station-Area Residents

	Coef.	Wald	Prob.
Socio-demographic Variables			
Auto ownership levels: No. of motorized vehicles per household member 16 yrs. or older	-2.523	5.512	.032
Higher income: Annual Household income $75,000 or more (0-1)	1.117	4.356	.041
Neighborhood Design			
Street lighting density: Number of street lights per 1000 feet of shortest walking distance from residence to nearest station	0.146	3.328	.116
Constant	2.394	3.743	.089
Summary Statistics No. of Cases = 90 Chi-Square (sig.) = 12.4 (.000) ρ^2 (McFadden) = .245			

riders with higher incomes were generally more likely to walk or bike to a station, even after controlling for car ownership levels; this possibly represents the greater health consciousness of upper-income transit users. It was expected that some of the neighborhood design variables measured for one-mile buffers around each surveyed housing project – e.g., street connectivity indices, retail shops, residential densities, presence of street trees and furniture – would have influenced the willingness of station-area residents to walk or bike to stations. Somewhat surprisingly, only one urban-design variable entered the equation, and it had modest predictive powers. Bright lights evidently sway some station-area residents to walk or bike. Good illumination is particularly valued in the evening after work. In general, the access choice model is as notable for variables that did not enter the equation (notably the absence of neighborhood design variables) as for those that did.

6. Ridership and Self-Selection

The previous analyses revealed an appreciable ridership bonus associated transit-based living. This bonus is thought to be significantly a product of self-selection, as suggested by the attitudinal variable previously discussed in Table 1. Those with a predisposition for transit-oriented living, the argument goes, conscientiously sort themselves into housing within an easy walk of a rail stop. That is, being near transit and being able to regularly get around via trains and buses weighs heavily in residential location choice. High ridership rates are simply a manifestation of this lifestyle preference.

Boarnet and Crane (2001) argue that travel patterns are partly a result of the decision on where to live and this influence needs to be accounted for when studying how urban design, including TOD, influences travel behavior. Self-selection could be occurring for any number of reasons: to reduce the stress of driving to work, to save time and money, or to express one's support of "green" transportation. In an early article on this subject, Voith (1991) argued that residential sorting largely explained ridership gains during the 1980s along commuter rail lines in Philadelphia's middle-class suburbs.

This section empirically examines the influences of self-selection on transit ridership. Using data on travel diaries and locations of residences and workplaces from the 2000 Bay Area Travel Survey (BATS), a nested logit model is estimated. Whereas the analyses presented earlier were for those living near rail stations in California, the analyses that follow are for a random sample of all residents in the San Francisco Bay Area – those who live near as well as away from rail stations.

The selection of rail transit for commuting was nested within the choice of whether to reside within ½ mile distance of a rail station or not. Whenever inter-related hierarchical relationships exist, the independence assumption breaks down, producing potentially biased parameter estimates. It is the relatedness among subsets of utilities (e.g., transit riding and transit-oriented living) that violates the logit model's assumption of independence. Nested logit models, such as used by Lerman (1976) and Anas (1986) to account for the influences of residential location on travel demand, explicitly account for interdependence among alternatives.

Data and Model Structure

The chief database used to carry out the analysis was the 2000 Bay Area Travel Survey (BATS) which contains two days of activity information for members of 15,066 randomly selected households in the nine-county San Francisco Bay Area. San Francisco residents were excluded from the analysis since residential sorting is thought to hold mainly for non-central locations where high levels of transit services are limited to rail corridors. In dense cities like San Francisco, residential sorting becomes less relevant since high-quality transit is fairly ubiquitous. Also, commutes by motorized means were only examined since residential location is mainly influenced by regional transportation systems, like highways and rail transit, as opposed to neighborhood-scale bicycle and pedestrian facilities.

In the two-tier nested model, the upper tier gauged the binary choice of whether to live near rail transit or not and the lower level indicated whether or not rail was taken to work. Nested estimation occurred by weighing lower-level factors influencing rail mode choice in the estimation of upper-level residential location choice. Nested estimation acknowledges that the subset of utilities of mode alternatives is not independent of the utilities that explain transit-based tenancy.

The two-tiered nested logit model took the form:

$$P_{n,i|k} = \exp(V_{n,i|k})/[\Sigma_{j\in Cn} \exp(V_{n,j|k})] \qquad (1)$$

$$P_{n,k} = \exp(V_{n,k} + \theta_k I_k)/[\Sigma_{s=1,2} \exp(V_{n,s} + \theta_s I_s)] \qquad (2)$$

where, for the k[th] branch of the upper tier, the inclusive term, I_k, is:

$$I_k = \ln \Sigma_{j\in Cn} \exp(V_{n,j|k}) \qquad (3)$$

$P_{n,i|k}$ = probability person n chooses mode option i (e.g., rail) given location choice k (e.g., near rail station)
$P_{n,k}$ = probability person n chooses location choice k
C_n = choice set available to person n
$V_{n,j|k}$ = measurable component of utility for person n choosing mode option i given location choice k
$V_{n,k}$ = measurable component of utility for person n choosing location k
θ_k = estimated coefficient on inclusive term for location choice k.
s = 1 (near transit); 2 (away from transit)

The expression $\theta_k I_k$ captures feedback between the lower level (mode choice) and upper level (residential location choice), where feedback is presumed to occur simultaneously. The inclusive value parameter, θ, measures the correlation among the random errors terms due to unobserved attributes of commute-mode choice. Also referred to as a "coefficient of (dis)similarity", theta values close to one are suggestive of strong unobserved similarities between residential location and commute choice whereas lower values reveal weak similarities (Hensher and Greene, 2002).

Among variables entered into the utility expression of residential location choice were workplace location (within a mile of a rail stop, expressed as a 0-1 dummy), job accessibility via highway and transit networks, household characteristics (such as whether or not a traditional two-adult household), and personal attributes of adult members (such as race and profession). The lower tier of the nested model, estimated separately for those living near and away from transit, included information on workplace location and car ownership levels in addition to other conventional predictors of mode choice like travel-time ratios (over the transit versus highway network for each origin-destination pair), neighborhood densities, and personal attributes of trip-makers.

The dummy variable denoting whether a workplace was near rail appears in both upper and lower tier models. Its presence in the residential choice model is in keeping with theories on commute-cost minimization advanced by Alonso (1964) and empirically tested by Giuliano and Small (1993) and others. The workplace location variable appears in the lower nest, in part, as a refined metric of comparative travel times via transit versus highway for origin-destination pairs. As commonly used in mode choice modeling, travel-time ratios were computed using average peak-period centroid-to-centroid durations over the regional network. This resolution of analysis, however, is too coarse to reflect the potential door-to-door travel-time advantages of using transit when one's workplace is within walking distance of a train station. Thus more as a metric of travel-time benefits and convenience at the egress end of a trip, dummy variables denoting whether workplaces were within a 0 – ¼ mile ring and within a ¼ - ½ mile ring of a station were used to better capture the utility of rail commuting.

Descriptive Statistics and Nested Model Output

Among the 11,369 cases with complete data for variables used in multi-level modeling, most individuals (91.4 percent) lived beyond ½ mile of a Bay Area heavy-, light-, or commuter-rail station. More than 90 percent, moreover, got to work by private car. Simple statistics suggests that living near rail stops strongly influences commuting. Among those residing within ½ mile of a station, 19.6 percent got to work by rail transit; among those living beyond the ½ mile radius, the share was 8.6 percent (Chi-Squared = 157.1, probability = .000). The flip-side of this is that more than 80 percent of those living within a walking distance of a Bay Area rail station reached transit by a motorized mode. (This is appreciably higher than the share found in the previous sections for residents of TOD housing projects, likely due in part to the regional sample including predominantly single family residences within a half-mile of non-San Francisco stations.) Such simple cross-tabulations, of course, fail to control for other factors, like comparative travel times, that explain mode choice, not to mention overlooking the interdependence of residential location and commuting behavior.

The nested logit results are presented in Table 3. Full information maximum likelihood estimation was used in deriving estimates. Variables were included in models' utility expressions on the basis of theory as well as statistical fits. Partly because of smaller sample sizes but also because more variables were available for specifying commute-mode choice than residential location, better statistical fits were obtained at the lower than upper level.

Residential Location Choice

The upper-level model, shown on the left-hand side of Table 3, predicts whether someone lives within ½ mile of a rail station. The model results reveal that working within a mile of a rail station induces households to reside near transit, all else being equal. The one-mile workplace radius provided better statistical fits than the more restrictive ¼ and ½ mile radii, suggesting that being within not only a walking distance but also a convenient feeder bus connection of a work site weighs into residential location choices. Also instrumental in the choice to live near transit is job accessibility via both highway and transit networks. The more jobs that are within a 45-minute isochrone by

Table 3. Nested Logit Model Results for Upper Nest (Rail Location Choice) and Lower Nest (Rail Commute Choice)

	Upper Nest		Lower Nest: Rail Commute			
	Location Choice: Live Near Transit		Live Near Transit		Live Away from Transit	
	Coef.	T-Stat.	Coef.	T-Stat.	Coef.	T-Stat.
Location Factors						
Workplace within ¼ mi. of rail station (0-1)	--	--	0.703	8.53***	1.149	118.12***
Workplace ¼ - ½ mi. of rail Station (0-1)	--	--	0.477	3.33*	0.670	34.25***
Workplace within 1 mi. of rail station (0-1)	0.364	20.62***	--	--	--	--
Job accessibility index, highway network, jobs (in 100,000s) within 45 minute isochrone of residence	0.014	4.02**	--	--	--	--
Job accessibility index, transit network, jobs (in 100,000s) within 30 minute isochrone of residence	0.134	3.84**	--	--	--	--
Transportation Attribute						
Travel time ratio (transit network/highway network, centroid to centroid)	--	--	-1.422	104.04***	-1.806	693.30***
Household/Neighborhood Attributes						
0 cars in household (0-1)	--	--	3.467	38.39***	3.394	89.96***
1 car in household (0-1)	--	--	1.537	18.02***	0.709	34.61***
2 cars in household (0-1)	--	--	0.673	3.32*	0.400	13.87***
Lower income household, Annual household income < $40,000 (0-1)	0.527	25.28***	--	--	--	--
Traditional household (2 adults, 1+ dependents; mid-stage of lifecycle, adults 25-54 years of age) (0-1)	-0.273	13.03***	--	--	--	--
Neighborhood density (no. dwelling units, in 10000s, within 1 mi. radius of residence)	--	--	0.287	2.19*	0.219	7.91***
Personal Attributes						
Driver's License (0-1)	--	--	-1.235	7.546***	-1.564	35.11***
Age 55+ years (0-1)	--	--	--	--	-0.606	3.64**
Asian-American (0-1)	0.366	10.64***	--	--	0.264	3.41*
Hispanic (0-1)	0.215	2.24	--	--	--	--
Sales-Labor Profession (0-1)	-0.165	5.01**	--	--	--	--

Table 1 (continued)						
θ	0.269	7.29***	--	--	--	--
Constant	-2.396	99.31***	1.347	4.03**	1.985	0.33***
Summary statistics						
No. of cases		11,369		1,031		10,338
X^2 (prob.)		184.9 (.000)		435.1 (.000)		2,864.9 (.000)
Rho-squared		0.066		0.390		0.422
* = significant at .10 level						
** = significant at .05 level						
*** = significant at .01 level						

car over the highway network or within 30 minutes over the rail-bus network, the more likely one is to reside near a rail stop. The positive association with transit accessibility stands to reason, however why might highway accessibility also positively explain transit-based residency? This likely reflects the fact that many rail stations in the San Francisco Bay Area have good freeway access, with some lying in freeway medians. This raises the possibility that some households opting to reside near rail stops are also attracted by the close proximity to freeways. Also of note is the fact that the best predicting job-accessibility isochrone was longer for highways (45 minutes) than transit (30 minutes). This could reflect the willingness of commuters to endure more time in the privacy and convenience of their cars than the often-crowded conditions of mass transit during commute hours.

In terms of household attributes, the model suggests that lower-income households (making less than $40,000 annually) tended to be drawn to rail station areas, all things being equal. This could be due to public policies that promote below market-rate housing near California rail stops, especially in the redevelopment districts that surround many Bay Area stations. Under California law, at least 15 percent of housing produced in redevelopment districts must be leased or sold below market rates. On the other hand, being a traditional household – defined as two adults between the ages of 25 and 54 years with at least one dependent (normally a child) – discouraged transit-based residency. Traditional households presumably value other factors, such as lower density living and school quality, than proximity to transit when making residential choices.

Also positively associated with the decision to reside near rail stations were racial-ethnic and occupational attributes of adult household members. Asian-Americans and Hispanics tended to be more attracted to station areas than whites. This could reflect a cultural dimension, especially in the Bay Area where many residents are recent immigrants from Latin America and parts of Asia, bringing with them a heritage of transit-oriented living (Cervero, 1996). In contrast, those working in sales occupations and as laborers tended to shy away from rail locations. This negative association could reflect the car dependence of persons engaged in conduct door-to-door sales and laborers (e.g., construction workers) whose job sites regularly change.

An indicator that nesting is appropriate is compliance with the McFadden condition that holds the theta parameter on the inclusiveness term should lie within a 0-1 interval (McFadden, 1974). Both theta values meet this criterion and are statistically significant at .10 probability level or better. This suggests the presence of unobserved similarities between commuting choice and residential location.

Probabilities and Self Selection

The probability of commuting by rail (R) can be expressed as the sum of the joint probabilities of taking rail and living near transit, p(R & NT), and of taking rail and living away from transit, p(R & AT). These joint probabilities, in turn, can be derived from the conditional probabilities generated from the nested logit output:

$$p(R) = [p(R \,\&\, NT) + p(R \,\&\, AT)] = \{[p(NT)^* \, p(R \mid NT)] + [p(AT)^* \, p(R \mid AT)]\}. \quad (4)$$

Using equation 4, probabilities of rail commuting were computed for sampled households. Figure 5 represents a two-dimensional surface map derived by plotting estimated probabilities by places of residence (i.e., according to longitudinal-latitudinal coordinates) for those residing in two East Bay counties (Alameda and Contra Costa) served by the Bay Area Rapid Transit (BART) heavy-rail system. The figure reveals high rail-commute probabilities among those living near East Bay BART stations.

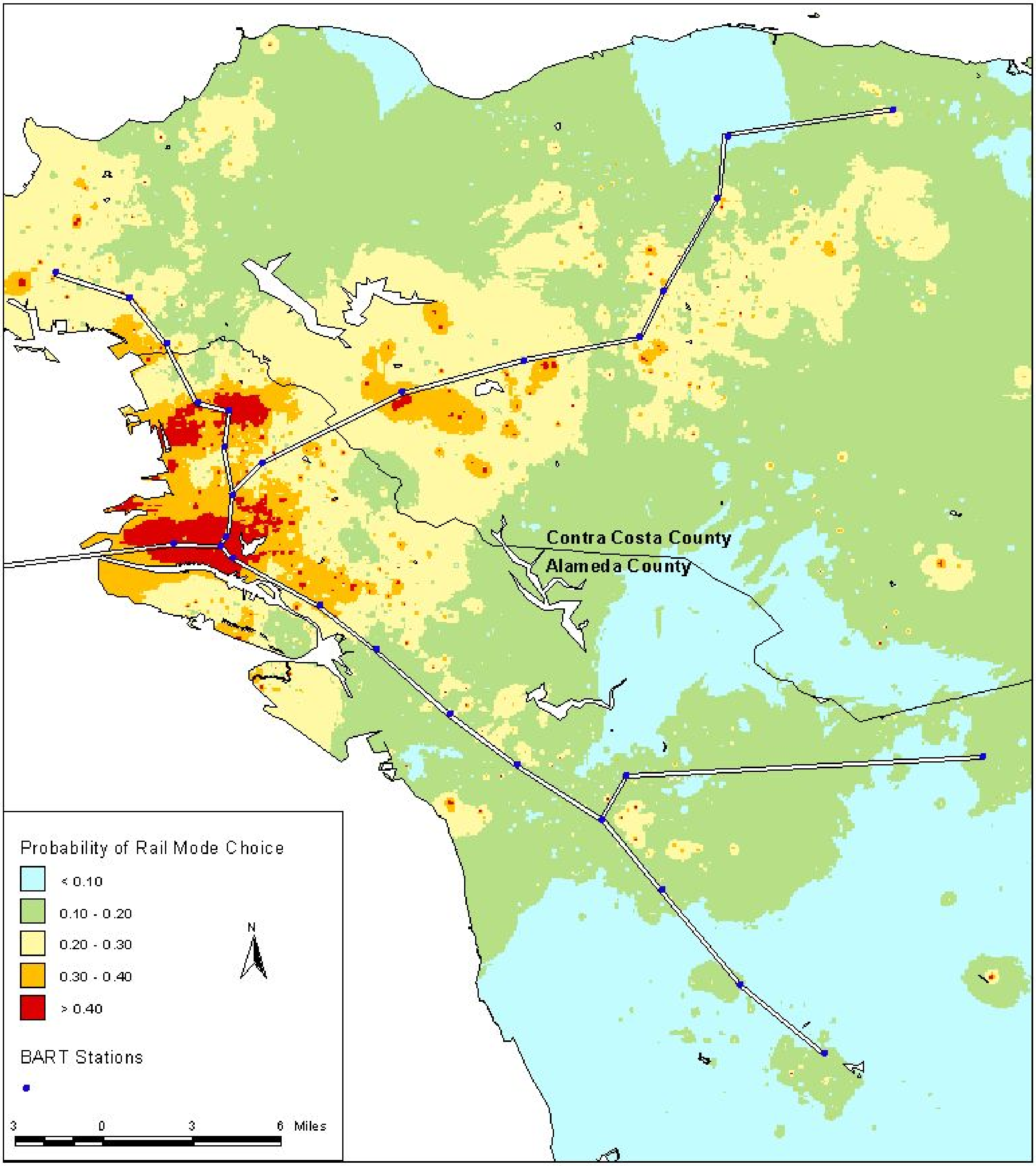

Figure 5. Estimated Probabilities of Rail Commuting Among Sampled East Bay Residents Using Conditional Probabilities

From the 11,533 sample cases for the Bay Area as a whole, the following average probabilities were computed for the upper and lower levels of the nested model:

$$p(NT) = .0880$$
$$p(AT) = .9120$$
$$p(R \mid NT) = .1547$$
$$p(R \mid AT) = .1144$$

where NT = “live near transit”, AT = “live away from transit”, R | NT = ”rail commute given live near transit”, and R | AT = “rail commute given live away from transit”. From these results the following joint probabilities can be computed:

$$p(R \,\&\, NT) = [p(NT)^* \, p(R \mid NT)] = (.0880)(.1547) = .0136$$
$$p(R \,\&\, AT) = [p(AT)^* \, p(R \mid AT)] = (.9120)(.1144) = .1043$$

Inputting these values into equation 4 produced an average probability of rail commuting:

$$p(R) = .0136 + .1043 = .1169$$

Thus, the model predicts that well over 90 percent of Bay Area households reside beyond ½ mile of a rail stop, comparable to the sample proportion. All else being equal, if a Bay Area worker lived near transit, the odds of rail-commuting was higher than if he or she lived away from transit – on average, a 15.5 percent versus 11.4 percent likelihood. Still, most workers living near stations were not likely to rail-commute: the average likelihood of not rail-commuting, 84.5 percent, was also in line with the sample proportion. The overall likelihood of rail commuting, regardless of place of residence, was 11.7 percent. The joint probability estimates reveal that a large majority of Bay Area rail commuters live away from transit, underscoring the importance of providing ample park-and-ride facilities and good bus feeder connections in serving this market.

The influence of self-selection on transit ridership can be inferred by comparing odds ratios based on mean conditional probabilities of rail commuters living near [p(R | NT)] versus away from [p(R | AT)] stations. For those living near stations, the average odds ratio of rail commuting is .1830 (.1547/.8453). Among those living beyond ½ mile of stations, the average ratio is .1292 (.1144/.8856). And among the entire sample, the mean odds ratio is .1324 (.1169/.8831). Thus, the odds of rail commuting are

41.6 percent [(.1830/.1292)*100] greater if one lives near versus away from transit, all else being equal. Compared to the typical Bay Area rail commuter, the odds of taking a train to work are 38.2 percent [(.1830/.1324)*100] higher for those residing near stations. By inference, the approximately 40 percent greater odds of rail commuting among those living near stations is due to proximity since the logit models directly controlled for the influences of other factors like comparative travel times, places of work, and socio-demographic characteristics of travelers and their households. This suggests that around 40 percent of the higher rail commuting shares among Bay Area workers living near transit is accounted for by self selection. Such an inference equates proximity to stations with residential self selection, once other factors are statistically controlled.

Sensitivity Test

From the nested logit results, a sensitivity test was conducted to show how probabilities of rail commuting varied as a function of three policy variables: residential location (within ½ mile of a station or beyond); workplace location (within ¼ mile of a station or beyond); and household car-ownership levels (0, 1, 2, 3+). The resulting sensitivity plot, shown in Figure 6, shows probabilities of rail commuting are very high among all groups when the worker lives in a zero-car household. Adding one car results in probabilities plummeting; they fall most precipitously for those residing and working away from stations. Working near transit and having no cars means there is a very high likelihood, well over 80 percent, of rail-commuting for both groups. Adding a car to the household results in the probability dropping far more sharply for non-station-area residents, however – notably, to below the probability (0.28) for station-area residents who work beyond ¼ mile of station. This suggests that an appreciable share of station-area dwellers who rail-commute do so out of choice rather than necessity, further hinting at self selection. Adding a second car to a station-area household, however, lowers the probability of rail-commuting sharply, below that of a non-station-area worker from a two-car household whose job site is near a rail stop. This indicates that the transit-ridership benefits of transit-based housing come from those with relatively

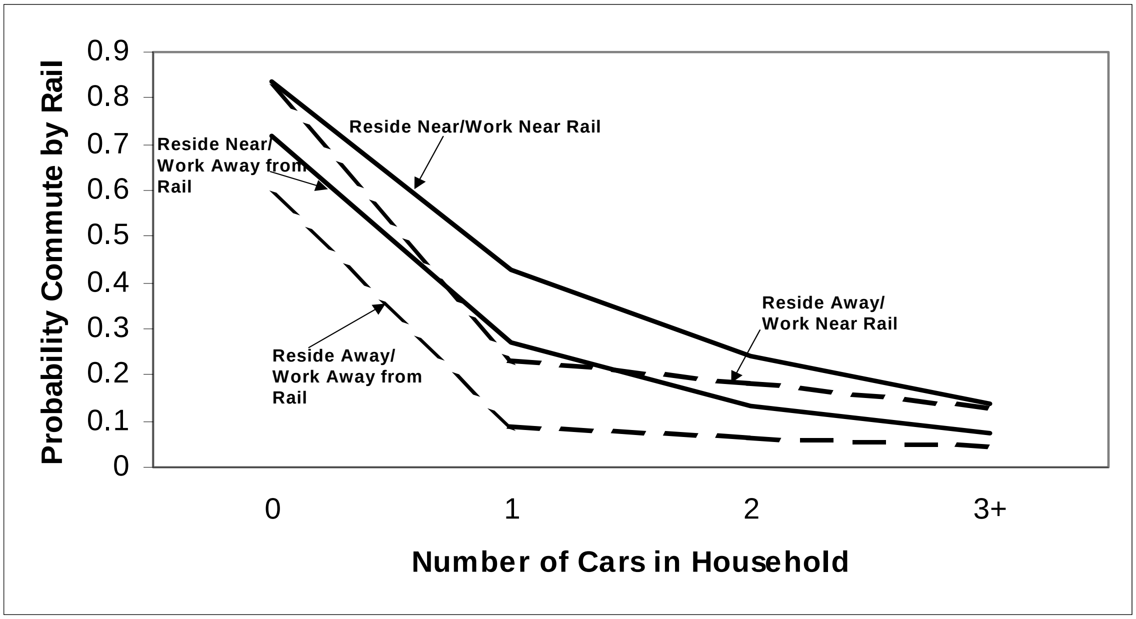

Figure 6. Sensitivity Plots of Rail-Commute Probabilities by Number of Cars in Household for Those Living and Working Near and Away from Stations. Reside Near = ½ mile or less; Work Near = ½ mile or less.

few – i.e., under two – cars in the household. This finding lends credence to the flexing of parking standards for housing near rail stations. It also supports the LEM concept of making it easier to qualify for a home loan if one resides near rail stops because of the tendency to ride transit more and own fewer cars. Holtzclaw et al. (2002) recently studied travel behavior and car ownership levels as functions of land-use and transit accessibility characteristics of neighborhoods in three regions with LEM programs: Chicago, Los Angeles, and San Francisco. A doubling of residential density was found to reduce household auto ownership and VMT per capita in the 32 percent to 43 percent range. The influence of transit accessibility on car ownership was less than that of density, but still appreciable.

7. Policy Implications

This research revealed a significant ridership bonus associated with transit oriented living, and further suggests that residential self-selection significantly accounts for this bonus. Self selection in no ways diminishes the importance of planning for and building transit-oriented residences. If the marketplace functioned perfectly, then a case might be made for governments to get out of the way so that producers and consumers can sort themselves into station areas unfettered. However, marketplaces are not perfect, whether due to homeowner resistance to new construction, exclusionary zoning, imperfect information, or negative externalities. Such frictions to residential mobility suggest there is a legitimate role for the public sector in breaking down barriers to freely made choices on where to live that in turn would help nurture TODs. Findings of self selection underscore the importance of breaking down barriers to residential mobility and introducing market-responsive zoning in and around transit nodes — zoning that acknowledges that those living near transit tend to be in smaller households with fewer cars. Flexible parking standards and location efficient mortgages would further "grease the path" toward self selection into TODs.

Several U.S. rail cities -- notably San Diego and Mountain View, California, Portland, Oregon, Bethesda, Maryland, and Arlington, Virginia -- have pro-actively zoned for housing near rail stations (Cervero, et al., 2002). Most, however, have focused on zoning for commercial development in hopes of producing higher property tax receipts than normally yielded by housing projects. In a review of land uses near more than 200 existing and proposed rail stations in Southern California, Boarnet and Crane (1998) found little evidence of zoning for residential TODs in local zoning ordinances. They inferred that, in Southern California at least, zoning for housing is viewed as less fiscally remunerative, thus conflicting with large economic development goals.

Besides supportive zoning, a number of other recent public policy initiatives have been introduced in recent years that could spur the production of transit-based housing. Besides the federally underwritten LEM program, another noteworthy federal action in the U.S. has been the allowance of transit agencies to sell land, such as parking lots, to private interests without returning the proceeds to the federal treasury. By converting parking lots to housing, the federal government hopes to boost ridership levels and thus the demand for government operating subsidies. To date, transit properties in Washington, D.C., Atlanta, Portland, Southern California, and the San Francisco Bay Area have exploited this new ruling to leverage affordable housing projects on former parking lots.

In the San Francisco Bay Area, several public agencies have been especially pro-active in promoting transit-based housing. The Metropolitan Transportation Commission has set aside $9 million under a Housing Incentive Program (HIP) as grant funds for local jurisdictions that locate compact housing near transit. To qualify for funds, a housing project must be within a one-third mile walk of a rail station, ferry dock, or bus route and provide at least 25 units per acre (10.1 units per hectare). Grants of $2,000 per unit are being provided for projects built at 60 units to the acre (24.3 units per hectare). Several Bay Area cities have used HIP grants to raise densities and increase the affordable component of transit-based housing projects. Even sub-regional governments have introduced incentive programs. The San Mateo City-County Association of Governments (C/CAG) authorizes $2,000 in State Transportation Improvement Program (STIP) funds for each bedroom built within one-third of a mile of a rail station and at a density of 40 units per net acre or more. In fiscal year 2000-2001, more than $2.2 million of STIP funds were transferred to local governments as a reward for adding more than 1,200 bedrooms in high-density housing near rail stops.

Lastly, this research underscores the importance of targeting workplaces, not just residences, to rail station areas. For TODs to yield ridership dividends, they must provide accessibility advantages over the private car, something which occurs by putting more destinations, like workplaces, near stations in addition to providing fast, frequent, and reliable transit services. Placing work sites near transit, however, is not enough. Free employee parking and other car subsidies will often prompt even those who live near transit to solo-commute. In California, at least, employer-based policies that eliminate free parking and provide good pedestrian access to job sites generally must be in place if TOD is to draw significant numbers of residents to trains and buses.

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