

**Residential choice, the built environment, and non-work travel: Evidence using new data and methods**

**Submitted to *Environment and Planning A*  
Additional minor changes, April 29, 2008**

Daniel G. Chatman, Ph.D.  
Bloustein School of Planning and Public Policy  
Rutgers University  
33 Livingston Ave, Suite 302  
New Brunswick, NJ 08901  
chatman@rci.rutgers.edu  
732.932.3822 x724  
732.932.2253 (fax)

Dan Chatman is an assistant professor of urban planning at Rutgers University.

Acknowledgments – Many thanks to Randy Crane, Mike Manville, Bob Lake, Mike Greenberg, Bill Rodgers, Ken Small, and three anonymous reviewers for their detailed comments and suggestions. The planning and implementation of the survey and the subsequent data cleaning and construction of built environment measures was funded by the California Department of Transportation, through a contract managed by Terry Parker. The survey was carried out by telephone interviewers from M. Davis & Company of Philadelphia. Thanks to Jim Brown, Morris Davis and other staff at that firm. This article is a significantly modified version of a chapter of my dissertation, funding support for which was provided by the Federal Highway Administration's Eisenhower Fellowship, the University of California Chancellor's Fellowship, and the Department of Urban Planning at UCLA.

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## **Residential choice and non-work travel: Evidence using new data and methods**

**Abstract.** Residents of dense, mixed-use, transit-accessible neighborhoods use autos less. Recent studies have suggested that this relationship is partly because transit- and walk-preferring households seek and find such neighborhoods. If so, and if the number of such households is small, policies to alter the built environment may not influence auto use very much. I argue that many of these studies are inconclusive on methodological grounds, and more research is needed. Here a purpose-designed survey of households in two urban regions in California is investigated using a new methodological approach. I find that most surveyed households explicitly consider travel access of some kind when choosing a neighborhood, but this process of residential self-selection does not bias estimates of the built environment's effects very much. To the extent that it does, the bias results in both underestimates and *overestimates* of the built environment's effects, contrary to previous research. The analysis not only implies a need for deregulatory approaches to land use and transportation planning, but also suggests that there may be value in market interventions such as subsidies and new prescriptive regulations.

## **1. Introduction**

People who live in densely-developed, transit-served neighborhoods with shops and services near their homes tend to walk and use transit more, and own and use autos less, than people who live in auto-oriented neighborhoods. Many planners and academic researchers have therefore argued for policies to encourage denser development, with a greater mix of uses, particularly near major transit stops. But this correlation between the built environment and auto use may be misleading, and if so, such policies might not have the intended effects.

The residential self-selection hypothesis, as conventionally framed, is as follows (e.g., Schimek 1996; Badoe and Miller 2000; Bento et al. 2001; Boarnet and Crane 2001). Households choose neighborhoods based on their expected travel patterns. Transit-seeking households are more likely to buy or rent homes near a stop on the line to work; people who shop a lot by car are more likely to find a place to live near a highway on-ramp; households who like to walk to the park choose neighborhoods with good parks within walking distance. This sorting process, if not statistically controlled, confounds the estimation of the neighborhood built environment's effects upon household travel. because if variation in the built environment leads to households spatially sorting themselves according to their travel preferences, then those preferences will be highly correlated with built environment characteristics.

But there are two more implicit parts of the residential self-selection hypothesis. The first is that people who seek accessible neighborhoods generally find them. If they did not, the correlation between pre-existing travel preferences and built environment

characteristics might not be strong enough to significantly bias estimates of the built environment's effects on travel. In addition, there would be an argument for deregulatory policies precisely to encourage more residential self-selection (Levine 1998).

The second implicit part is that a select group of willing households is reliant upon the built environment to “express their preferences” to use transit and to walk, while the remainder of the population is less responsive to built environment variation. But the opposite is also possible. People who like to walk might be more willing to walk longer distances; people who like to drive might not be dissuaded by traffic congestion caused by dense development; and so on.

Thus the residential self-selection hypothesis is, in a nutshell, really three non-mutually-exclusive hypotheses: (1) people decide where to live based on how they expect to travel (and their predictions are correct), (2) this sorting process is not significantly constrained, so preferences and built environment characteristics are highly correlated, and (3) self-selecters are more responsive to the built environment.

The truth or falsity of these hypotheses will likely vary by urban area, with differing policy implications. If the relationship between travel and the built environment depends on alternative-mode-seeking households living in dense, transit-accessible places, then the argument for government intervention depends on the size of that group, and whether the supply of such neighborhoods is significantly constrained. If households predisposed to use alternative travel modes already find neighborhoods that match their preferences, policy interventions may not make much of a difference. But it could be that a significant share of households seeking accessible neighborhoods is unsuccessful due to

land use regulations that constrain the supply of those neighborhoods. In that case one policy solution would be to relax those constraints, particularly in targeted areas (e.g., near transit stops). Finally, if the built environment influences even habitual auto users to use autos less, a more wide-scale adoption of policies to alter development patterns or relax policy constraints on development may be appropriate, and the argument for development subsidies and prescriptive regulation is strengthened.

This study builds upon existing literature, employing new methods of data collection and analysis. Households in two metropolitan areas in California, San Diego and the San Francisco Bay Area were surveyed. The data are used to analyze the relationships between the built environment, non-work travel frequency by mode, and residential choice. This study focuses on non-work travel because non work travel is a substantial majority of household travel in the United States, accounting for 81 percent of trips and 73 percent of distance traveled in the most recent nationwide survey of travel, the 2001 NHTS (Hu and Reuscher 2004).

## **2. Theory**

Empirical evidence strongly suggests that households simultaneously choose their housing unit and neighborhood along with the anticipated mode and duration of their trip to work (e.g., Lerman 1976; van Ommeren, Rietveld, and Nijkamp 1999; Cervero and Duncan 2002), although other criteria can dominate choices for some households (Giuliano 1991). Do households also choose where to live based on access to non-work activity locations—such as parks, shops, doctors' offices, movie theaters, and child care establishments? As long-distance commuting has become less difficult with improved

automobile technology (Rouwendal and Nijkamp 2004), and work trips comprise a diminishing share of household travel, perhaps non-work travel does have a greater influence on residential choice. But three main factors discussed below—bundling, the investment characteristics of homes, and supply constraints—imply that non-work travel preferences are not likely to play a dominant role.

First, housing is purchased jointly with neighborhood goods, local goods, and accessibility to activities (e.g., Goodman 1989; Mills and Hamilton 1989). Non-travel goods in the bundle include the crime rate, municipal services, school quality, the racial/ethnic mix, and microclimate (Tiebout 1956; Giuliano 1991; Giuliano and Small 1993; Wachs et al. 1993). A preferred rank ordering for all of these choice dimensions may be impossible (cf. Arrow 1963), and the complexity of the decision may lead households to prioritize a few salient characteristics (e.g., a safe neighborhood) and ignore less important ones, in a process of “satisficing” (Simon 1957). For some households travel accessibility will not be a priority.

Second, homeowners must take into account the resale value of the house which depends partly on how *others* value its characteristics (Fischel 2001; Fennell 2006). This makes it somewhat less likely that transit- and walk-preferring households are willing to pay a premium for transit and walk access, because they are likely in the minority.

Third, the supply of neighborhoods with high non-work travel accessibility via alternative modes—as measured by higher development density, proximity to shops, proximity to transit, dense street grids, and proximity to job centers—may be significantly constrained in housing markets with strict land use regulations such as San

Diego and the San Francisco Bay Area (see, e.g., Cervero 1989; Levine 1998; Glaeser and Gyourko 2002; Levine, Inam, and Torng 2005). Any such constraint on supply is likely to lower the probability that households who prefer walk or transit access to non-work activities manage to locate in such neighborhoods.

### **3. Empirical literature**

Recent research has not resolved the extent to which correlations between residential built environment characteristics and household non-work travel reflect a function of a market-sorting process or are an independent function of the built environment. Four kinds of research design are employed: analyses of land value and travel accessibility; simultaneous models of residential location and travel; studies of travel behavior before and after residential moves; and studies using reported attitudes as measures of travel preferences.

Land value studies can provide indirect support for the hypothesis that people choose where to live based on access to retail and other non-work destinations, in the form of evidence whether households pay more for proximity to those destinations. The evidence here is mixed. For example, Song and Knaap (2003) found that commercial proximity, land use diversity, and ease of walking increase property values, while Srour, Kockelman and Dunn (2002) found no evidence of a relationship between residential land value and walking access to parks and shops.

The second approach relies upon multiple-equation estimation to model the household's joint choice of where to live, and how to habitually travel. Boarnet and Sarmiento (1998) Boarnet and Crane (2001), and Khattak and Rodriguez (2005) all used

the instrumental variables approach to create “predicted values” for built environment characteristics that are based on a first-step equation modeling residential choice. Boarnet and Sarmiento (1998) and Boarnet and Crane (2001) found that their predicted measures were substantially less statistically significant than the uncorrected measures, implying that the built environment influences non-work auto trip frequency only via a process of residential self-selection. In contrast, Khattak and Rodriguez (2005) found that their predicted values for a binary “neotraditional” variable did not change results much in comparison to observed values.

The instrumental variables technique has its problems, chief among which is reduced efficiency (resulting in lower levels of statistical significance), and the difficulty of finding appropriate instruments (Gujarati 1995: 604-605). Boarnet and Crane (2001) test their instruments and find they are statistically appropriate in only one case. Khattak and Rodriguez (2005) do not report carrying out a test, but they apply the technique using a variable (“neotraditional”) that takes on only values of 0 and 1 which likely leads to relatively little variance between predicted and observed values.

Using a nested logit simultaneous model of activity scheduling and residential location with a one-day activity diary from Massachusetts, Ben-Akiva and Bowman (1998) found empirical evidence that neighborhood choice was conditioned on anticipated activity schedules, implying that non-work travel preferences may play a strong role in residential location choice. Bagley and Moktharian (2002) employ a structural equations model (SEM) of commute and non-work travel, the built environment, and travel-related attitudes (as discussed in more detail below). While the

SEM method is promising because it can account for mutual causality, the results are often difficult to interpret, variables must conform to the assumption of normality or be transformed, and in this case (as sometimes occurs with SEMs) the estimation routine required significant truncation of the dataset.

The third approach has investigated household travel before and after a move. With data from the Puget Sound Transportation Panel, Krizek (2003) found that higher neighborhood and regional accessibility after moving were associated with lower vehicle distance traveled, a greater number of vehicle tours, and a lower number of stops per vehicle tour. Based on a survey in Northern California, Handy, Cao and Mokhtarian (2006) found that residents reported walking more frequently after moving into neighborhoods that they said were more accessible than their previous neighborhoods.

The before-and-after approach does not test the residential self-selection hypothesis directly, although it can be combined with other methods. One cannot know whether alternative-mode-preferring households sought neighborhoods enabling the new travel patterns, or whether the moves were largely unrelated to the travel accessibility of the new neighborhood. This approach may show that movers alter their travel behavior when moving to certain environments, or that changes in the built environment due to a move are associated with changes in travel behavior, but the method cannot by itself account for the possibility that movers seek out such environments.

The fourth approach is the reported-attitudes strategy, in which answers to questions about household attitudes and preferences relating to travel are used as proxy variables to control for residential self-selection. Mokhtarian, Cao, Schwanen, Handy,

and co-authors have used this strategy in combination with structural equations and quasi-longitudinal approaches (Kitamura, Mokhtarian, and Laidet 1997; Bagley and Mokhtarian 2002; Schwanen, Dieleman, and Dijst 2004; Schwanen and Mokhtarian 2004; Schwanen and Mokhtarian 2005; Cao, Handy, and Mokhtarian 2006; Handy, Cao, and Mokhtarian 2006; Cao, Mokhtarian, and Handy 2007). I discuss two early studies from this set. Using data from households in five San Francisco Bay Area neighborhoods, Kitamura, Mokhtarian and Laidet (1997) initially found statistically significant relationships between the built environment characteristics of people's neighborhoods and their trip-making and mode choices. However, when measures of respondent attitudes toward travel and residential location were included, the built environment measures declined in significance. Bagley and Mokhtarian (2002) estimated a structural equations model of commute and non-work travel by mode. Two attitude variables were modeled as a function of the built environment and travel, while a large number of others were treated as independent, including whether the household believed that having shops and services near home is important; that public transportation is a good option in situations when driving is too expensive; and that driving alone is preferable. Many of these attitudinal variables were significantly related to distance traveled by mode, while only in one case were either of the two built environment factors significantly related to travel. In a somewhat different implementation of the strategy, Khattak and Rodriguez (2005) use reported attitudes as instruments in a first-stage equation predicting whether households choose to live in a neotraditional neighborhood. These variables include responses to questions about whether having a back yard is important, whether it is nice

to have a house near the sidewalk, and whether new development consumes too much land.

The reported-attitudes strategy is problematic because stated attitudes of households about travel, travel-related topics, and the built environment could themselves be influenced by characteristics of the neighborhoods that the households have chosen, as well as by people's travel behavior in the new neighborhood. First, people may alter their attitudes, or their reports of their attitudes, to be consistent with their chosen neighborhoods, in response to "cognitive dissonance" (Festinger 1957). Experiments by social psychologists have shown that "after making important decisions, we usually reduce dissonance by upgrading the chosen alternative and downgrading the unchosen option" when asked to rate alternatives before and after making a choice (Myers 2002: 151). Rather than attitudes causing behavior, people will often change their attitudes when their attitudes conflict with their behavior.

The relevance of cognitive dissonance in travel behavior and travel-related attitudes has been shown empirically. A Los Angeles study employing simultaneous equations models showed that perceptions of the attributes of transit buses influenced, and were influenced by, habitual commute mode. Under one specification, behavior influenced attitudes but the initial effect of attitudes on mode choice was rendered statistically insignificant in the simultaneous model (Reibstein, Lovelock, and Dobson 1980). A study near Amsterdam showed evidence that solo driver attitudes about carpooling were negatively influenced by construction of a new carpool lane, implying a process of cognitive dissonance or self-justification (VanVugt et al. 1996). In another

study in the Netherlands, respondents confronted with the estimated environmental impacts of their auto driving over an eight-week period were more likely to alter their reported attitudes to be less “pro-environment” than to commit to changing their driving habits (Tertoolen, van Kreveld, and Verstraten 1998).

In addition to the influence of travel habits on attitudes, attitudes may also genuinely change over time either because of new travel habits, due to exposure to a new environment, or due to changes in the household (e.g., Schwanen and Mokhtarian 2004). The net result of cognitive dissonance and of other changes in attitudes is that households may be more likely to report that “having shops and services close by is important to me” if they have ended up living in a place with shops and services close by, even if they chose the neighborhood for unrelated reasons.

Reported attitudes and preferences about travel or about the current neighborhood and built environment may both be influenced by cognitive dissonance in a way that can bias analysis—not only if travel attitudes are affected by current travel habits, but also if neighborhood or built environment attitudes are influenced by the chosen built environment, and if the built environment influences travel. Thus, like attitudes about travel, attitudes about the built environment (or about sprawl, or about neighborhoods) cannot be treated as independent influences on travel.

#### **4. Research design**

The research method employed here is a variant on the reported-attitudes approach described above. I surveyed households about how they decided where to live at the time of their most recent move, and their travel for a 24-hour period. Respondent

answers to the questions about the residential search process were used to construct variables representing pre-move preferences. The cognitive dissonance phenomenon is elicited when people are confronted with a conflict between the values they hold and their actual behavior, and the questionnaire aims to reduce that conflict. The questions to elicit residential choice criteria are asked before questions about travel, and the questions themselves elicit previous search criteria rather than current preferences. Both differences should produce measures that more closely track pre-move travel preferences both because they are less subject to post-move changes in preferences that are caused by the built environment itself, and because they are less subject to alterations in reports of current preferences caused by cognitive dissonance.<sup>1</sup>

These attempts to reduce cognitive dissonance may not be entirely successful. But the expected direction of any residual analytical bias due to cognitive dissonance is clear. Like current reported preferences, contemporaneously-reported search criteria will be more highly correlated with travel behavior and the current residential environment than criteria at the time of the search. Therefore cognitive dissonance will cause false negatives, not false positives, when measuring built environment influences; that is, findings of statistical insignificance of built environment variables are less reliable than are findings of statistical significance.

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<sup>1</sup> Handy, Cao and Mokhtarian (2006) and Cao, Mokhtarian and Handy (2007) include questions about “preferred neighbourhood characteristics” “when looking for a new place to live,” in addition to questions about attitudes toward travel. It is not clear whether these questions explicitly elicited search criteria at the time of the most recent move. These variables are not substituted for attitudinal variables in the models, but are employed along with them.

#### **4.1. Data**

A computer-aided telephone survey was administered between November 2003 and April 2004 to a stratified random sample of households living in the San Diego metropolitan area and in the three core counties of the San Francisco-Oakland-San Jose metropolitan area. The design included an over-sample of households living near twelve selected rail stations in the two metropolitan areas (for details on station area selection, see Chatman (2005: 199-217)). Respondents without listed telephone numbers in the station areas were recruited to call a toll-free number while other households were telephoned directly. The survey collected travel, demographic, and socioeconomic information, including 24 hours of complete activity data using a retrospective activity diary format similar to that used in the American Time Use Survey. The interview was completed by 1,113 adults. Average interview time was 25 minutes, with 10 percent of the sample requiring more than 40 minutes. Only those respondents who provided sufficient address information for their homes to be geocoded, and who were responsive to the questions about residential choice, were included, leaving 999 respondents in the data set used for analysis.

The survey included questions about what respondents considered when choosing their current neighborhoods, based in part on questions on the Los Angeles Family and Neighborhood Survey (Sastry et al. 2000). About 74 percent of households had moved in the previous ten years (slightly higher than, but comparable to the counties in the study area, which ranged between 67 and 72 percent as of Census 2000). Follow-up questions

determined which travel modes were of interest at that time. Both questions were asked early in the survey, prior to travel or demographic questions.

The first residential location question was:

When people move, they choose a new house or apartment and also choose a new neighborhood. Please think back to what kind of neighborhood you were hoping to find when you moved in [move year]. What were some things that you looked for? *After each response, probe:* What else did you look for? *If respondent says housing cost or rent was important, probe:* Given that you had to find a neighborhood that you could afford, what were some other things that you were looking for?

There were 15 precoded responses (see Table 1 for a complete list). Reasons not falling within these categories were recorded verbatim, and recoded into the relevant travel-related categories in post-processing.

[Table 1 about here]

The 532 respondents who stated that they prioritized their own commute, the commute of another household member, a household child's school trip, or access to shops/services were asked follow-up questions regarding specific modes—for example:

For your personal commute to school or work, which transportation modes were important considerations in deciding where to live? You may choose more than one. Walking, biking, rail, bus, or personal vehicle (such as a car, van, SUV, pickup truck, RV or motorcycle)?

Multiple responses were allowed to each of the four such follow-up questions, and were used to create the search criteria variables described in the next section.

Response rates for the metropolitan area strata and station area households with known telephone numbers ranged between 20 and 24 percent, based on Council of American Survey Research Organization standards. For those recruited via the mail, the completion rate was about seven percent (a lower bound of the response rate because it

does not account for vacant units or incorrect addresses). The net response rate sample-wide approaches 20 percent. While the low response rates do present a concern for the representativeness of the sample for population description purposes, they pose a substantially less significant concern for the validity of the comparative analysis among subgroups that is presented here (see, e.g., Groves 1989, p 5). The data were to be used primarily in estimating differences between subgroups of people, and demographic characteristics are controlled. More details on the survey, survey dataset and built environment data sources are available in Chatman (2005: 171-198).

#### **4.2. Dependent variables**

The three dependent variables are the number of non-work trips by auto (including motorcycles and carpools), transit (bus or rail), and walk/bike. Respondents were asked to provide destination type for all activities during a 24-hour period. They provided information for about 80 percent of activities outside work, home, or school. Non-work trips made up 83 percent of those carried out outside home, work, or school; the remaining 17 percent were pick-up and drop-off trips not otherwise categorizable. Return trips are excluded from the analysis. For segmented trips, mode is assigned based on the longest-duration segment.

About 40 percent of respondents did not engage in a non-work activity outside the home on the survey day, but all respondents are included in the analysis to avoid non-random sample truncation. The average number of trips to access non-work activities was 1.24, 36 percent of the average total number of trips of 3.42 (which includes return trips home). Auto and other personal vehicles accounted for 77 percent of non-work trips,

much lower than the average for the regions, reflecting the stratified sample which over-represented transit-proximate, walk-accessible areas.

[Table 2 about here]

### **4.3. Independent variables**

**Search criteria variables.** Respondents' answers to the residential location question and to the follow-up questions about specific modes were used to create dummy variables set equal to one, and otherwise to zero (Table 3, below). For example, if the respondent reported that the commute to work was an important criterion, and if both auto and transit were mentioned as relevant modes, then the variables "Sought auto access for any purpose" and "Sought transit access for any purpose" were set equal to one, and all others were set equal to zero. In subsequent regression analysis the variables were sometimes combined, as described below. They were also recoded for some households in post-processing to account for those verbatim responses not initially categorized as being travel-access-related.

**Built environment variables** were measured near the home (geocoded by street address or in some cases nearest cross streets) using circular buffers. Measures consisted of the number of retail workers within a 1/4 mile and a one mile radius; residents per road mile within one-mile; four-way street intersections within 1/4-mile, presence of a heavy rail station (BART or Caltrain) within 1/2-mile, presence of a light rail station (San Diego trolley or Santa Clara Valley Transit Authority light rail) within 1/2-mile; distance to the nearest major central business district (San Diego, San Jose, Oakland, or San Francisco); and whether there is a sidewalk on both sides of the street (Table 2). All but the self-

reported sidewalk measure were calculated in a computationally intensive GIS process using electronic parcel, Census block, transportation analysis zone, and street maps. See Chatman (2005) for further details. In addition to these, stratum dummy variables are included to partly control for any effects of the stratified sample design not captured by other independent variables (Table 2). These variables show that the sample was 59 percent Bay Area, and 41 percent San Diego County, with Bay Area and San Diego selected station areas making up 35 and 24 percent of the total respectively.

**Control variables** include household income; income squared; household size; sex of respondent; whether children live in the household; an interaction of these two (female respondent with children in household); whether the person worked outside the home on the survey day for two hours or more; and whether the survey day was a weekday (Table 2).

#### **4.4. Model form**

Estimating the influences of the built environment and residential preferences on non-work trip frequency requires a modeling technique that accounts for the discrete count nature of the dependent variable (Cameron and Trivedi 1998). Here a version of the negative binomial model is used in which the variance is parameterized as a quadratic function of the expected mean.

Although not a simultaneous modeling process, a set of count models has advantages. Unlike a multinomial mode choice model, it takes into account both the share and the number of trips by each mode, and can be used to investigate mode substitution

and induced travel simultaneously. It is not as prone to respondent error as is a model of distance traveled (e.g., a VMT model).

The vector of independent variables includes measures likely to directly influence trip making by one of the three modes, because these measures may have indirect effects on trip frequency by the other modes. For example, the auto trip frequency model includes transit access and pedestrian connectivity as independent variables in order to test whether by increasing trip making by transit and walking, these built environment characteristics decrease auto trip making. Thus each of the three mode-specific trip frequency models can be thought of as a reduced form version of a simultaneous system of equations across modes.

## **5. Results**

Four interrelated research questions are addressed here:

1. What share of households explicitly considers non-work access specifically, and travel access generally, when choosing where to live?
2. Do households who report seeking neighborhoods with good travel access successfully find such neighborhoods?
3. Does any residential sorting of households according to travel preferences confound conventional estimates of the built environment's effects on travel?
4. Does the built environment have different effects on those with strong and weak travel preferences?

### **5.1. Who considers travel access when choosing a neighborhood?**

Access to shops and services was the second most highly sought-after neighborhood characteristic, at 22 percent of the sample, just after low crime (24 percent of the sample) (Table 1, above). “Access to transit” was mentioned by 21 percent of the sample; the respondent’s commute length, 18 percent; highway proximity, 11 percent; commute length for another adult in the household, 10 percent; and a child’s trip to school, 5 percent. In all, slightly more than half of respondents (53 percent) cited travel access of some kind when asked what they sought when choosing a neighborhood. Since everyone needs to be within some distance of other people and places, these answers are best understood as distinguishing households who strongly prioritized travel access from those who prioritized other criteria.

Households who prioritized travel access were younger, smaller, and had lived in their homes for 1.8 fewer years on average. They were significantly less likely to mention the type of people living in the neighborhood (e.g., families with children, people of the same race/ethnicity), the crime rate, having family and friends nearby, or their familiarity with the area (based on chi-squared tabular frequency tests, not shown here). They were also less likely to say that they restricted their search to neighborhoods with a particular kind of housing (e.g., where more apartments or large houses were available). But at the same time, these households were also substantially more likely to have competing search priorities. Two-thirds also cited at least one other search criterion, compared to 38 percent of the group that did not cite travel access.

The answers to the follow up questions about travel mode are summarized in Table 3. Respondents could cite more than one mode; for example, 4 percent of respondents said they sought auto, transit *and* walk/bike access for some travel purpose. Among respondents seeking access for any travel purpose, transit-only seekers made up the largest group at 14 percent of respondents. (As described above, the survey oversampled households living near selected rail stops.) Restricting the group specifically to those who sought access to shops and services, the largest group was those who sought walk/bike access (5 percent). Summary categories are also shown in Table 3.

[Table 3 about here]

## **5.2. Do households with strong travel preferences find matching neighborhoods?**

Simple regressions are used to test the correlation between built environment measures and the share of households reporting that they sought travel access (Table 4). Possible confounding factors, such as demographic characteristics, are not controlled. The intention is to determine whether households that report seeking a certain kind of access obtain such access at a higher rate than those who do not.

[Table 4 about here]

Households who sought good walk or bike access to shops and services live in neighborhoods with an average of 1,020 more retail workers in the quarter mile area near home (a one-standard-deviation increase in activity density). Those who sought transit access to shops or services live an average of 9,635 feet (about 1.8 miles) closer to a rail stop. Households who sought auto access for any purpose live in areas with 130 fewer residents per road mile in the mile radius near home (a 1/2-standard-deviation decrease).

Finally, 74 percent of households who sought transit access live within a half-mile of a rail station, versus 58 percent of the remainder (chi-squared 25.6, one degree of freedom,  $p$ -value  $< 0.001$ ). These regressions show that households who report that they sought travel access at the time of the most recent move are more likely to live in neighborhoods with good access via the desired mode, although the relationship is far from determinative.

### **5.3. Do access-seeking households travel differently, and does this lead to biased estimates of built environment influences?**

Do access-seeking households travel differently? Results from regressions of trip frequency by mode on the two sets of search criteria variables (corresponding to the search criteria summarized in the top portion of Table 3, above) are presented in Table 5. Exponentiated coefficients (incidence risk ratios) are shown, indicating the relative frequency of trip making compared to the base group (the “None” category in Table 3).

There are strong relationships between the neighborhood search criteria and the frequency of non-work trip making by mode. Households seeking walking and bike access for any purpose make only about half as many auto trips as the base group (column 1), and those seeking the same type of modal access for shops and services make about 60 percent as many (column 2), while those who sought both auto and transit access for any travel purpose make about 40 percent *more* auto trips (column 1). Those who sought transit access or transit and walk/bike access make from four-and-a-half to almost six times the number of transit trips as the base group (columns 3 and 4). And those who sought walking access (including those who sought it in combination with some other mode(s)) make between 1.8 and 5.1 times as many walk trips, while those

who sought auto access only (for any travel purpose) make just 40 percent as many walk/bike non-work trips (columns 5 and 6).

[Table 5 about here]

Does the high correlation of travel preferences, as measured by search criteria, with built environment measures (see Table 4) along with the high correlation of those pre-existing preferences with observed travel (Table 5), lead to biased estimates of the built environment's influences on travel? This question is addressed in the next step of the analysis, which simultaneously controls for pre-existing travel preferences, built environment measures and socioeconomic characteristics.

We begin with regressions of personal vehicle, transit, and walk/bike trips on built environment measures and socioeconomic controls, then add a parsimonious set of the preference dummy variables to those regressions (Table 6). Only variables that are statistically significant in at least one of the models are shown. Socioeconomic control variables are not discussed. The models are built using the set of seven "any travel purpose" search criteria variables (first columns of Table 3), as those variables are more highly significant (as shown in Table 5) and more relevant than the more narrowly defined "shops-and-services" search criteria variables.

For the models shown in columns 2, 4 and 6 of Table 6, the set of seven search criteria variables is winnowed down to one or two (sometimes combined together as one variable, e.g., "sought walk or transit access") based on the analysis shown in Table 5 along with a series of likelihood ratio tests. The final likelihood ratio model tests, displayed at the bottom of the table, suggest that the models presented here are

statistically indistinguishable from models with the full set of preference variables. All statistically significant search criteria variables are retained, and the omission of the others hardly affects the coefficients on the built environment variables.

[Table 6 about here]

Accounting for pre-existing travel preferences in this way does not change measured built environment relationships very much (Table 6). The change in coefficients for the nine statistically significant built environment measures is in all cases less than 10 percent, and in all but two cases less than 3 percent. In the base auto trip model, the only statistically significant built environment measure is the number of residents per road mile (column 1). This measure is intended to represent road congestion due to intense development, and is empirically associated with lower road speeds in this dataset (Chatman Forthcoming). Each additional 1,000 residents per road mile is associated with 0.45 times as many non-work auto trips (Table 6, column 1), or 55 percent fewer trips. The next model (column 2) includes the two statistically significant search criteria variables for this model, representing households who sought both transit and walk/bike access in one group, and households who sought auto along with either transit access, walk access, or both in the other group. Adding these two statistically significant search criteria variables to the auto trip model, while improving the model fit, hardly changes the built environment coefficients.

Non-work transit trip frequency is about six percent lower for each additional 1,000 retail workers in the one-mile radius around home, almost seven times as high among households with a heavy rail station within one half mile, and 20 percent lower for

each mile farther away from the nearest downtown (San Diego, San Francisco, Oakland or San Jose), where bus service is best (column 3). The model including search criteria (column 4) shows that all else equal, households who sought some form of transit access make about five times as many non-work transit trips as the remainder of the population, but accounting for this preference changes the built environment coefficients very little.

Finally, walk/bike non-work trip frequency is 3.2 percent higher for each additional four-way intersection within a quarter mile of home (a measure of pedestrian connectivity); four percent lower for each mile further away from downtown, where pedestrian-oriented retail uses may be less common; 67 percent higher if there is a sidewalk on both sides of the street near home; and about 50 percent lower near light rail stations, which may be less pedestrian-friendly than the metropolitan average (column 5). Having sought auto access (only) is associated with halving the walk/bike trip frequency rate, while having sought walk/bike access or transit access is associated with twice the number of walk/bike trips (column 6). Including these variables changes the built environment measures somewhat more than in the auto or transit trip frequency models. The magnitude and statistical significance of the effects is reduced, but in each case less than 10 percent, and all but the coefficient on the sidewalk variable remain significant at the 10 percent level or better.

Note that the changes that do occur in the auto and transit non-work trip frequency models actually marginally *increase* the statistical significance and the magnitude of the measured built environment relationships. In these cases, accounting for residential self-selection with this method seems to result in stronger built environment

relationships (although whether the changes themselves are statistically significant is not tested). The opposite is true for the walk/bike model. The implications are explored in more detail in the next section.

#### **5.4. Are built environment relationships different for households with strong travel preferences?**

In the final stage of analysis I investigate whether built environment effects appear to be different for groups of households with different search criteria. The regression models shown in Table 6 are modified by interacting the search criteria variables and the built environment measures; those equations are presented in Table 7 (displaying built environment measures only). There are no statistically significant differences among groups in the auto trip frequency model, even when the most likely candidates are entered one set at a time, so the auto trip model is not shown.

There are two main findings. First, there are relatively few differences in the effects of the built environment among households prioritizing travel access and the base group. Second, in the transit and walk/bike models, there is evidence that some built environment characteristics have stronger “effects” on the travel of households who did *not* seek access by that mode, as well as more conventional evidence that built environment effects are restricted to households seeking travel access.

[Table 7 about here]

For about half of the built environment variables, the results are so far from significant that the interactions are dropped entirely from the models. These include network load density, heavy rail access, and sidewalk availability. For the transit model, retail density at the one-mile radius is also dropped. The remaining built environment

variables are allowed to vary across the two groups, and are boxed in the table.

Coefficients that are statistically different from *each other* at the 10 percent level or higher are bolded.

We begin with the transit model. Following the conventional expectation of the residential self-selection hypothesis, households who sought transit access make 45 percent more transit trips for each additional 1,000 retail workers nearby, while there is no statistically distinguishable effect for the base group. But those who did *not* seek transit access make about 10 percent more transit trips for each additional four-way intersection near home, while those who did seek transit access are not responsive to pedestrian connectivity. Meanwhile, light rail access has a larger positive impact on transit trip making for those who did not seek transit access than for those who did (although the effect for neither group alone is statistically distinguishable from zero).

In the walk/bike trip model (column 2), the single significant difference is that higher retail within one mile of home is associated with lower walk/bike trip frequency among auto-access seekers than the remaining group. Perhaps auto seekers are more likely to substitute auto for walking when shopping is within a short drive but a long walk. Some of the remaining results, though not statistically significant, are interesting. The correlation of walk/bike trips with retail within a quarter mile of home is quite high for those seeking auto access and nearly absent for those seeking either walk/bike or transit access. Higher pedestrian connectivity is more highly associated with the walk/bike trip frequency of those who sought auto access than it is with either those who

sought walk/bike access or transit access, or the base group. Again, however, these statistically insignificant differences are only suggestive.

## **6. Conclusions**

This study adds to a body of research evidence that residential self-selection leads to mis-estimation of the built environment's influences on travel. But the measured bias due to residential self-selection with these methods and data is modest, for the most part reducing the size of estimated relationships rather than rendering them insignificant. This study also provides new evidence that households seeking travel access are sometimes *less* responsive to the built environment, contrary to the way that the residential self-selection hypothesis is conventionally framed. Residential self-selection may actually cause underestimates of built environment influences, because households prioritizing travel access—particularly, transit accessibility—may be more set in their ways, and because households may not find accessible neighborhoods even if they prioritize accessibility.

The empirical models employ a set of seven search criteria dummy variables to represent travel preferences along with eight more finely-measured built environment variables. This is in contrast to some previous research that has included a large number and variety of variables measuring travel-related attitudes, and a smaller number of less sensitively measured built environment variables. Future research could explicitly test the sensitivity of results to including more and better measures of pre-existing preferences and of the built environment.

The results are relevant to development policy, though further research is needed to confirm and expand upon the implications. A deregulatory approach—such as eliminating height restrictions, low-density residential zoning, parking requirements, and road level-of-service requirements—may be just a first step, and one insufficient for significant change in travel behavior in many regions. Where households actively seeking transit- or walk-accessible neighborhoods are in the minority, the market for such development may be small.

But the larger group of households that does *not* seek out walk- and transit-accessible neighborhoods may be responsive to the built environment nonetheless. Because this larger share of the population will not demand such development, prescriptive regulations may be appropriate. Such policies might include maximum parking requirements, maximum level-of-service road standards, or minimum lot-line standards, or even restricting the supply of land to drive up its cost and therefore the density of development. Advocating such policies requires a much more careful accounting of the social welfare arguments for intervention than can be given here, including a more explicit assessment of the external costs of auto use, the external benefits of transit use and walking, and evidence that households' demand for low-density, outlying neighborhoods does them more harm than good due to long commutes, social isolation and sedentary lifestyles.

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## 8. Tables

**Table 1: Neighborhood characteristics sought in most recent move**

	N	Percent of total
Low crime	240	24%
<b>Access to shops and services</b>	<b>219</b>	<b>22%</b>
Visual characteristics of the neighborhood	219	22%
<b>Transit access, generally</b>	<b>213</b>	<b>21%</b>
<b>Length of commute for respondent</b>	<b>182</b>	<b>18%</b>
Housing quality	141	14%
<b>Highway access, generally</b>	<b>109</b>	<b>11%</b>
<b>Commute of other adult(s) in household</b>	<b>98</b>	<b>10%</b>
Characteristics of neighborhood residents	85	9%
Public schools	70	7%
Familiarity with the neighborhood	62	6%
<b>Child's trip to school</b>	<b>53</b>	<b>5%</b>
Near family and/or friends	44	4%
Proximity to open space	40	4%
Moved with someone	19	2%
Other factor recorded verbatim	281	28%
Second other factor recorded verbatim	11	1%
Third other factor recorded verbatim	4	0.4%

Totals do not add to 100 percent because multiple responses are permitted.

Excludes 14 households with no response and 100 households without geocoded home locations.

**Table 2: Travel, built environment and socioeconomic variables**

<b>Variable Type / Name</b>	<b>Units</b>	<b>Mean</b>	<b>St Dev</b>	<b>Max</b>
<b>Dependent variables</b>				
Auto non-work trips	Count	1.02	1.44	10
Transit non-work trips	Count	0.05	0.27	3
Walk/bike non-work trips	Count	0.28	0.72	6
<b>Built environment variables</b>				
Retail employees (1/4-mi radius)	Count	696	1,198	8,975
Retail employees (1-mi radius)	Count	5,696	6,863	55,175
Residents per road mile	Count	448	220	1,458
Heavy rail station within 1/2-mile	Indicator variable (1=yes)	0.24	0.43	1
Light rail station within 1/2-mile	Indicator variable (1=yes)	0.41	0.49	1
Distance to downtown (CBD)	Miles	7.82	6.79	45
4-way intersections (1/4-mi radius)	Count	11.74	9.92	53
<b>Survey stratum dummy variables</b>				
In San Diego metro area	Indicator variable (1=yes)	0.41	0.49	1
In Bay Area metro area	Indicator variable (1=yes)	0.59	0.49	1
In Bay Area selected station area	Indicator variable (1=yes)	0.35	0.48	1
In San Diego selected station area	Indicator variable (1=yes)	0.24	0.42	1
<b>Socioeconomic variables</b>				
Age	Mid-point of standard ranges	46.16	17.04	85
Female	Indicator variable (1=yes)	0.57	0.50	1
Children in household	Indicator variable (1=yes)	0.22	0.41	1
Female with children	Indicator variable (1=yes)	0.14	0.35	1
Weekday	Indicator variable (1=yes)	0.76	0.43	1
Worked two hours or more	Indicator variable (1=yes)	0.41	0.49	1
Household size	Count	2.22	1.31	10
Household income	\$10,000	5.69	3.79	11.00

Notes: N=999

**Table 3: Search criteria variables**

	Sought access for any travel purpose		Sought access to shops/services	
	N	Pct.	N	Pct
Auto only	119	12%	37	4%
Transit only	136	14%	26	3%
Walk/bike only	47	5%	54	5%
Auto and transit	48	5%	12	1%
Transit and walk/bike	91	9%	37	4%
Auto and walk/bike	50	5%	35	4%
Auto, transit and walk/bike	41	4%	17	2%
None	467	47%	781	78%
-----				
Summary categories (overlapping)				
Auto	258	26%	101	10%
Transit	316	32%	92	9%
Walk/bike	229	23%	143	14%
-----				
Total	999	100%	999	100%

**Table 4: Built environment measures regressed on search criteria (OLS)**

<b>Dependent Variable</b>	<b>Mode Sought (Indep. Var.)</b>	<b>Coeff.</b>	<b>t</b>	<b>P&gt; t </b>	<b>R-sq.</b>
Retail workers, 1/4-mi	Walk/bike to shops/services	1,020	9.88	0.000	0.0892
	Walk/bike for any purpose	701	8.02	0.000	0.0606
Feet to nearest rail station	Transit to shops/services	-9,635	3.1	0.002	0.0095
	Transit for any purpose	-8,388	4.36	0.000	0.0187
Pop. + emp. / road mileage, 1-mi	Auto to shops/services	54	0.82	0.412	0.0007
	Auto for any purpose	-130	2.89	0.004	0.0083
Pop. + emp. / road mileage, 3-mi	Auto to shops/services	-55	1.72	0.087	0.0029
	Auto for any purpose	-76	3.47	0.001	0.0119

Absolute value of t-statistics in brackets. Statistical significance: \*=10%, \*\*=5%, \*\*\*=1%

**Table 5: Non-work trips by mode regressed on search criteria (negative binomial model)**

	Auto trips		Transit trips		Walk/Bike trips	
	(1) Sought access for any travel purpose	(2) Sought access to shops / services	(3) Sought access for any travel purpose	(4) Sought access to shops / services	(5) Sought access for any travel purpose	(6) Sought access to shops / services
Auto only	1.055 [0.37]	0.968 [0.13]	0 [0.02]	0 [0.01]	<b>0.398</b> <b>[2.18]**</b>	0.895 [0.23]
Transit only	1.016 [0.11]	1.005 [0.02]	<b>5.151</b> <b>[3.98]***</b>	<b>4.694</b> <b>[2.44]**</b>	<b>2.886</b> <b>[4.68]***</b>	<b>2.367</b> <b>[2.01]**</b>
Walk/bike only	0.725 [1.36]	0.717 [1.51]	0.828 [0.18]	1.356 [0.45]	<b>4.032</b> <b>[4.44]***</b>	<b>4.12</b> <b>[5.08]***</b>
Auto and transit	1.155 [0.69]	1.371 [0.80]	1.621 [0.60]	2.034 [0.60]	<b>2.115</b> <b>[2.09]**</b>	0.789 [0.28]
Transit and walk/bike	<b>0.481</b> <b>[3.73]***</b>	<b>0.602</b> <b>[1.84]*</b>	<b>5.988</b> <b>[4.03]***</b>	<b>4.617</b> <b>[2.81]***</b>	<b>5.132</b> <b>[6.90]***</b>	<b>3.582</b> <b>[3.78]***</b>
Auto and walk/bike	<b>1.42</b> <b>[1.76]*</b>	1.161 [0.62]	0 [0.01]	0 [0.01]	<b>1.895</b> <b>[1.76]*</b>	1.488 [0.96]
Auto, transit and walk/bike	1.329 [1.29]	1.366 [0.94]	<b>4.746</b> <b>[2.56]**</b>	5.743 [2.38]**	<b>2.641</b> <b>[2.67]***</b>	0.835 [0.26]
Observations	999	999	999	999	999	999
Log likelihood	-1384.3	-1392.5	-180.1	-190.6	-606.41	-625.8
Log likelihood, constant only	-1396.4		-201.2		-645.8	

N=999. Absolute value of z statistics in brackets (statistical significance: \* 10%, \*\* 5%, \*\*\* 1%).

**Table 6: Trips by mode regressed on built environment measures and search criteria**

Nonwork trips by mode type	Auto		Transit		Walk and Bike	
	(1) Base Model	(2) Search Criteria	(3) Base Model	(4) Search Criteria	(5) Base Model	(6) Search Criteria
Sought transit and walk/bike access		0.586 [2.72]***				
Sought auto, plus walk/transit access		1.259 [1.84]*				
Sought transit access				4.866 [4.55]***		
Sought auto (only) access						0.483 [1.70]*
Sought walk and/or transit access						2.118 [4.34]***
Retail density, 1/4-mile radius	0.916 [1.20]	0.926 [1.06]	1.189 [1.17]	<b>1.257</b> [1.79]*	1.032 [0.36]	0.998 [0.03]
<i>Retail workers, 1,000s</i>						
Retail density, 1-mile radius	0.978 [1.57]	0.977 [1.63]	<b>0.938</b> [1.78]*	<b>0.924</b> [2.08]**	1.011 [0.71]	1.01 [0.68]
<i>Retail workers, 1,000s</i>						
Network load density, 1-mile radius	<b>0.45</b> [2.21]**	<b>0.438</b> [2.30]**	0.32 [0.98]	0.369 [0.90]	1.438 [0.66]	1.432 [0.67]
<i>Population per road mile, 100s</i>						
Heavy rail access within 1/2 mile	1.264 [1.27]	1.295 [1.40]	<b>6.998</b> [2.91]***	<b>6.89</b> [3.00]***	1.316 [0.88]	1.211 [0.64]
<i>BART or Caltrain station</i>						
Light rail access within 1/2 mile	1.103 [0.53]	1.088 [0.45]	0.943 [0.08]	1.578 [0.62]	<b>0.479</b> [1.93]*	<b>0.522</b> [1.75]*
<i>S.D. Trolley or SCTVA station</i>						
Distance to nearest downtown	1.003 [0.31]	1.003 [0.30]	<b>0.827</b> [2.74]***	<b>0.835</b> [2.58]***	<b>0.956</b> [1.99]**	<b>0.964</b> [1.71]*
<i>Miles</i>						
Pedestrian connectivity, 1/4-mi radius	1 [0.03]	1.002 [0.33]	1.016 [0.68]	1.006 [0.29]	<b>1.032</b> [2.90]***	<b>1.026</b> [2.49]**
<i>Four-way intersections</i>						
Sidewalk on both sides of street	1.146 [1.02]	1.124 [0.88]	0.798 [0.41]	0.522 [1.16]	<b>1.672</b> [1.68]*	1.522 [1.41]
Observations	999	999	999	999	999	999
Log likelihood	-1358.8	-1352.5	-167.16	-155.72	-573.15	-559.05
Log likelihood, constant-only model		-1396.4		-201.2		-645.8
Likelihood ratio test - comparison to model with all search criteria variables:						
Chi-squared	N/A	1.99	N/A	2.42	N/A	2.86
Degrees of freedom		5		4		5
Probability that models are equivalent		0.85		0.66		0.72

N=999. Absolute value of z statistics in brackets (statistical significance: \* 10%, \*\* 5%, \*\*\* 1%).

Note: Statistically significant built environment measures in bold type. Socioeconomic and stratum dummy variables (Table 2) are included in all models but not displayed. Complete results are available from the author.

**Table 7: Transit and walk/bike trip regressions with built environment effects varying by group**

Independent variables	(1) Transit trips		(2) Walk/bike trips		
	Base group	Transit seekers	Base group	Walk or transit seekers	Auto seekers
Sought transit access		27.332 [3.91]***			
Sought walk or transit access				1.607 [1.34]	
Sought auto access (only)					1.219 [0.24]
Retail density, 1/4-mile radius <i>Retail workers, 1,000s</i>	<b>0.707</b> [1.32]	<b>1.449</b> [2.58]***	1.024 [0.16]	0.997 [0.04]	2.531 [0.76]
Retail density, 1-mile radius <i>Retail workers, 1,000s</i>	0.933 [1.82]*		1.026 [1.12]	1 [0.00]	<b>0.33</b> [1.91]*
Network load density, 1-mile radius <i>Population per road mile, 100s</i>	0.271 [1.15]		1.507 [0.75]		
Heavy rail access within 1/2 mile <i>BART or Caltrain station</i>	6.584 [2.95]***		1.173 [0.52]		
Light rail access within 1/2 mile <i>S.D. Trolley or SCTVA station</i>	<b>3.299</b> [1.45]	<b>0.615</b> [0.55]	0.405 [2.00]**	0.582 [1.32]	2.454 [0.72]
Distance to nearest downtown <i>Miles</i>	0.839 [2.48]**		0.961 [1.81]*		
Pedestrian connectivity, 1/4-mi radius <i>Four-way intersections</i>	<b>1.097</b> [2.26]**	<b>0.984</b> [0.67]	1.007 [0.39]	1.032 [2.63]***	1.159 [1.67]*
Sidewalk on both sides of street	0.607 [0.84]		1.534 [1.41]		
Log likelihood		-151.3			-553.5
Log likelihood, constant only		-212.7			-645.8

N=999. Absolute value of z statistics in brackets (statistical significance: \* 10%, \*\* 5%, \*\*\* 1%).

Coefficients in boxes vary by group; remaining coefficients held equal across groups.

Bolded coefficients statistically distinguishable from *each other* at the 5 percent level or higher.

Socioeconomic and stratum dummy variables (see Table 2) included but not shown.