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Abstract:

This paper examines the nature of land use based substitution effects on travel modes, identified by Greenwald, examining the direct impact of land uses inducing trip-making behaviors. These impacts are analyzed in the context of trip chaining, defined here as consolidating two or more non-home activities in a single departure from home. The findings suggest rather than strictly promoting one type of transportation over another, the regional impact of localized urban design practices is to consolidate trip making behavior closer to the home. As such, urban design "carrots" must be complemented with policy "sticks" in order to promote true exchanges of travel modes.

Land Use Influences on Trip Chaining: Evidence from Portland, Oregon

1. Introduction

Investigations in travel behavior have suggested land use induced substitutions of travel modes are not as unambiguous as some might claim. The most famous supporters of the proposition are scholars and practitioners of neo-traditional urban design, which argues that greater orientation toward grid street patterns, increases in mixed land uses as defined by greater intensity and balance between residential and commercial activities, greater retail employment density, better access to mass transit will all necessarily lead to reduced use of automobiles (and the associated social ills), because of enhanced convenience of other travel modes.[1,2,3,4] In contrast, Crane demonstrated that because urban form simultaneously reduces the time requirements for all modes of travel, if the increased convenience for vehicle travel is stronger than the increased convenience for walking, these modifications to urban form could, unintentionally, induce more vehicle trips.[5] Crane's point goes directly to the question of travel mode substitution: are neo-traditional design practices inducing individual travelers to walk more, drive less, both or neither? While the third option would be the ideal for neo-traditional design proponents, there is no *a priori* reason to believe that simply because walking becomes easier that this will automatically reduce the number of automobile trips made.

The purpose of this paper is to examine how land use based substitution effects on travel behaviors manifest, by examining the direct impact of land uses inducing trip-making behavior. These impacts will be analyzed in the context of trip chaining. Trip chaining is defined here as consolidating two or more non-home activities in a single departure from home, thus reducing the total amount of travel time required for completing the set of activities. In that context, a single chain begins and ends at home, with all trips made in between as elements of that specific chain. A better understanding emerges of how land use affects travel behavior by examining the impacts on trip chains and chain elements, since trip chaining best reflects the reality of most trip making decisions.

2. Previous Research

Crane's discussion has helped to shape the research agenda on the effect of land use practices on travel mode substitution. This body of work has produced several interesting points. First, it appears that where land use does affect travel mode usage, it does so through affecting travel times for various modes.[6,7] Second, using this relationship between land use and travel time, it appears that practices consistent with neo-traditional design (e.g., smaller lot sizes, grid oriented street structures, better access to transit and retail employment) appear to be effective in changing the substitution rate for walking compared to driving. According to Greenwald, land use practices consistent with neo-traditional principles reduce travel times proportionally more for walking than for driving, and thus increase the proportion of walking trips made in comparison to driving.[8] Further, the effect is not strictly linear; small adjustments to individual land use measures towards or away from practices consistent with neo-traditional design guidelines can lead to a cumulatively large benefit or detriment to observed travel mode splits. Thus, the whole is greater than simply the sum of its constituent parts. The substitution argument is further supported by Krizek's findings from the Puget Sound area; the author concluded that relocation of residence to more pedestrian accommodating neighborhoods with greater availability of neighborhood retail did, in fact, result in lower vehicle miles traveled, overall number of trips and tours (i.e., trip chains) made.[9] This substitution effect does have practical limitations. Greenwald found the effect for land use does not appear to be as solid for transit substitution for personal vehicle use, as compared to walking substitution for automobiles, and the magnitude of effect on walking mode splits, while statistically significant, was small.

Since pedestrian accommodating urban environments cut times more significantly for walking compared to driving by manipulating urban form, the traveler should change his or her activity patterns and travel mode choices to fully take advantage of the lowered travel times. In his investigation of suburban activity patterns Rodriguez found evidence to support this position, concluding ". . . that increased numbers of walking trips came at the expense of automobile trips, consistent with prior evidence."[10] This raises the question, what might be the consequences of these pattern and mode choice changes? Downs explained how improvements to one type of travel mode lead to a re-optimization of travel all behaviors in terms of scheduling, mode choice and total number of trips, a process he calls triple convergence. Downs argues this alteration of behavior takes place up to the point where the time savings to the individual traveler are lost, except now more travel is taking place.[11]

Though triple convergence was proposed in the context of vehicle travel and highway improvements, Crane's explanation of how urban form affects all modes of travel simultaneously broadens the applicability of triple convergence; regardless of the laudable travel mode substitution effects a pedestrian friendly urban form generates, the new equilibrium of travel behavior for various modes could conceivably wipe out the environmental and time savings benefits by putting more cars on the road, for a greater number of total trips, while simultaneously inducing more walking and transit behavior.

So, how does one begin to test if the effects of urban design on travel mode substitution are, in fact, beneficial? One measure widely accepted by both promoters and critics of the impact of policy and urban form on travel behavior is distance traveled by travel mode type.[12,2,13]

The fundamental assumption is that higher values for distance automatically imply more travel by the specific travel mode type. The researchers in this debate are not generally in contention over this assumption, but rather the relative effectiveness of the various forms of intervention (both policy and urban design based) in achieving reductions in the underlying trip making behavior and/or desired outcomes (e.g., reduced traffic congestion, enhanced environmental quality, etc.).

Optimizing time spent traveling is also served by consolidating activities at the same location whenever possible; wherever urban design facilitates consolidating activities, that in turn could have effects on travel mode selection and overall number of trips made. This idea is at the heart of activity based trip modeling strategies. Pas made important early contributions to the discussion, first by describing how clustering travel activities into nominal categories can explain significant proportions of the underlying travel behavior variance[14], and second, by presenting results that suggest weekday travel touring patterns represented by these nominal categories are independent of the day of the week they take place (e.g., an individual's preferred pattern of making several linked stops, or multiple separate trips to and from home, does not change from Monday or Tuesday to Thursday or Friday).[15] Recker refined Pas' contribution by describing how interactions among household characteristics and urban form variables contributed to activity patterns for individuals within households, then subsequently developing an activity modeling framework based on individual utility maximization for activity participation.[16,17]

The findings of Pas and Recker, respectively, simplify subsequent investigations into the relationship of urban form on travel behavior, such as the ability of jobs housing balance to influence regional travel mode splits by Cervero,[18,19] and Kockelman's work on the influences of land use density and design on personal travel mode choice.[20,21] Because urban form is static, any attempt to use it in measuring travel behavior patterns which are dynamic in time and space, without also adjusting for cyclical patterns (e.g., day of the week), could become unwieldy if Pas' assumptions were not established. For example, Kockelman concluded that accessibility, balance and diversity of economic activities had modest positive influences on walk/bike travel mode selection in the San Francisco Bay area.[20] Were it not for Pas, Kockelman's work would additionally need to account for daily changes in the relative utility between travel modes in order to draw conclusions about the impacts of urban form on mode selection.

Finally, Kitamura, et. al. extended the discussion by explaining that home location affects choice of destination in trip chains because, all other things being equal, travelers attempt to minimize travel costs by choosing destinations which are closer to the home, if any return to the home is anticipated in the context of the immediate tour.[22] A logical extension of Kitamura's point in the current context is to analyze the effect of urban form for the home location on trip chaining behavior. Resting on the behavioral assumptions identified by Kitamura and Pas, we begin the current investigation.

3. Data and Models

The models tested in this and subsequent sections use the urban form variables employed in related investigations of travel mode substitution in the Portland, Oregon area by Greenwald.[8] Specifically, these are 1.) The 1994 Household Activity and Travel Diary Survey (1994 Travel Diaries), conducted by Portland Metro, the regional planning authority;[23] 2.) the 1998 release of the Regional Land Information System geographic information systems shape files, also distributed by Portland Metro;[24] and 3.) the 1990 Summary Tape File 3 data produced by the United States Bureau of the Census.[25] Figure 1 places the region in the context of the western

United States generally, while Figure 2 provides a more detailed overview of the region and the dispersal of home locations of travel survey participants.

The 1994 Travel Diaries were collected by Portland Metro between April 1994 and April 1995, surveying 10,048 persons in 4,451 households in the four county area surrounding the city of Portland (i.e., Multnomah, Clackamas, Washington and Clark County). All members of each household were surveyed for two consecutive days (including weekends) and asked to log details on all activities which either generated a trip, or took longer than 30 minutes to complete.

In total, 50,623 trips were identified in the 1994 Travel Diaries. Trips were given unique identifier numbers which allowed them to be tied back to traits of the individual and household that generated them. In addition, Portland Metro generated shortest network distances between trip origin and destination using the EMME2 network model for the survey area.

Using the trips identified in the 1994 Travel Diaries, and employing the definition of trip chaining described earlier, the authors identified 5,479 chains within the 1994 Travel Diary data set. From each chain the authors were able to generate chain length (i.e., trip counts) and travel distance, both in total and separately for pedestrian, transit (bus and light rail combined) and automobile travel modes. Equation 1 provides the general model for trip chain analysis:

(Equation 1) $$\boldsymbol{Y}_{im} = \mathbf{X}\boldsymbol{\beta}$$

where $\boldsymbol{Y}_{im}$ is the column vector of specific measures of chain and mode adjusted dependent variable (i.e., distance, number of chains, or individual trips by mode type in a chain) for an individual person i, $\boldsymbol{\beta}$ is the column vector of regression coefficients, and $\mathbf{X}$ is the matrix of independent variables made up of the following:

X_1 = Dummy variable for gender (1 = Female, 0 = Male)
X_2 = Dummy variable for race (1 = Non-white, 0 = White)
X_3 = Age
X_4 = Age squared

X_5 = Dummy variable for handicap constraining travel mode selection (1 = Yes, 0 = No)
X_6 = Number of Children in the household
X_7 = Dummy variable for employment status (1 = Yes, 0 = Otherwise)
X_8 = Income
X_9 = Income squared
X_{10} = Average variable vehicle cost for vehicles in the household (cents per mile)
X_{11} = Ratio of cost of transit trip (measured in cents) to average variable vehicle cost
X_{12} = Dummy variable for possession of a driver's license (1 = Yes)
X_{13} = Number of Vehicles in the household
X_{14} = Dummy variable for multiple phone lines in the household (1 = Yes)
X_{15} = Average parcel size (in acres) within a half mile of the center of the home Transportation Analysis Zone
X_{16} = Average parcel size (in acres) within a half mile of the center of the home Transportation Analysis Zone
X_{17} = Mixed Use index value for the home Transportation Analysis Zone
X_{18} = Number of street intersections within a half mile of the center the home Transportation Analysis Zone
X_{19} = Total employment in the home Transportation Analysis Zone
X_{20} = Retail employment in the home Transportation Analysis Zone
X_{21} = Number of bus stops within a half mile of the home
X_{22} = Distance (in feet) to the bus stop nearest to the home
X_{23} = Number of light rail stops within a half mile of the home
X_{24} = Distance (in feet) to the light rail stop nearest to the home
X_{25} = Inverse Mills estimation for household residing in low/medium/high pedestrian accommodating urban form

With respect to the individual traveler, the standard battery of sociodemographic variables (i.e., race, age and gender) are included as controls. Additionally, square of age and having a physical handicap affecting travel decisions are included to account for aspects of travel behavior tied to physical ability of the individual. Initially, as a person matures physically they gain stamina, so they might be willing to substitute more physically intense travel if they perceive other benefits associated with one particular mode. For example, a person might decide to walk more as they get older because they have the ability to do so, and they perceive the potential health benefits as an additional incentive. However, because diminished physical capacity is also a characteristic of both young and old extremes of the age spectrum, there is the possibility of a non-linear relationship between age and travel mode substitution.

Number of children and employment status represent additional constraints on individual travel behavior. Travel needs of children often need to be satisfied by the parent, representing an external influence on the travel behaviors of adults. Employment also factors in as a travel constraint since other activities (and thus related travel behavior) are often organized to accommodate work schedule; this effect should be attenuated for those workers who have flexible scheduling.

Elements of the trip chaining models not related to scheduling generally reflect household wealth, per trip out of pocket costs and preferences of the individual traveler. To address the wealth and trip cost issues, the authors include household income (and income squared, reflecting the diminishing marginal utility of income), average household vehicle cost, and the relative cost of transit travel compared to the average vehicle cost in the household. Average household vehicle cost is used rather than specific vehicle cost because trip logs did not specify which vehicle in the household was used for vehicle based trips.[*] Transit system fares for the survey periods were provided by Tri-Met, the regional transit provider for the Portland metropolitan area.[†] Household income measures for the 1994 Travel Diaries was put into an ordinal coding scheme in increments of $5,000, with a top category of $60,000 or more. Ordinal classification schemes of this type artificially constrain the variability of the underlying variable. The authors of this work follow the strategy employed in previous research[7,28,8] calculating average values for the log of income for each category, and then exponentiating these averages. The limitation of this strategy is that it reduces the variability within each category by centering all observations within a group (e.g., all households in the category of $15,000 - $19,999 have a value of $17,500, regardless of what their actual household income may be).

Number of vehicles available in the household and is included as an indicator of preference for vehicle travel; possession of a driver's license is also included as an additional control variable, since it reflects viability (rather than simply preference) of vehicle use for the individual. The existence of multiple phone lines per household are taken as and willingness to substitute communication for travel. Because use of telephone lines within a household is mutually exclusive, it is reasonable to expect that as the number of telephone lines increased, total number of trips would drop as household members engaged in alternatives to trip making (e.g., social calling, electronic purchasing, telecommuting, etc.).

The land use densities for trip origins used in this model are similar to those used in other models analyzing non-automotive behavior, specifically in relation to the jobs housing balance literature[18,19] and recent attempts to analyze non-work travel behavior in relation to urban form of the home environment.[6,7,29,8] Most land use measures in the 1994 Travel Diaries are collected at the transportation analysis zone (TAZ) level, which was most consistent with 1990 census block group geography. Average parcel size within a half mile of the center of the TAZ and number of intersections in the TAZ are included in this work because they jointly inform the model of the underlying urban design. Smaller average parcel sizes with a higher number of intersections implies a higher density grid network for street orientation over a given area. Distance and number of transit stops in proximity to residential locations are collected as measures of access and range of choice, respectively, for non-automobile travel options.

The mixed use index for the TAZ was calculated by Portland Metro using the following formula:

$$\text{Index} = \frac{((HH * (Emp * Factor))}{((HH + (Emp * Factor))}$$

where:

HH = Number of households within a half mile of the center of the specific transportation analysis zone.
Emp = Total employment within a half mile of the center of the specific transportation analysis zone.
Factor = Average number of households within a half mile of the center of a TAZ/Average number of jobs within a half mile of the center of a TAZ, for all TAZs in the Portland Metro area

The result of the formula is a continuous index which is near zero when there is a relative lack of either jobs or households, and highest when both the proportion is even and the number of households and jobs is high.

While land use measures are presumed to be exogenous influences on travel behavior, previous investigations have acknowledged the potential for endogeneity between urban form and travel behavior, resulting in a potential sample selection bias. For example, recent results by Handy, et. al. suggest that benefits of policy and infrastructure alterations (such as changes in zoning and pedestrian environment improvements) may be attenuated by personal preferences and attitudes towards physical activity.[30,31] More generally, individuals might base their travel behavior on the characteristics of their surrounding neighborhood, or the household which an individual is part of might choose to live in a neighborhood which best accommodates their travel behavior; or there might be some interactive behavior between both these aspects in the selection of a particular residential location. Weisbrod, et. al. identified factors that might differentially affect relocation choices (and hence associated travel behavior patterns) when viewed in conjunction with housing tenure, including household size, income, job location and neighborhood traits (e.g., taxes, density, crime, school quality).[32]

Boarnet and Greenwald[6,7,28] dealt with endogeneity in earlier land use-travel behavior research using instrumental variables. Alternatively, Heckman suggested selection bias might be addressed by developing discrete choice models to estimate the utility of being in the observed state for each case in the dataset.[33] Using this model, it would then be possible to construct case by case estimates of the ratios of probability density functions and cumulative density functions for these estimated utility values (Heckman identifies these ratios as the Inverse Mills Ratio), and include this as an additional variable in the main model, thus accounting for the selectivity bias. This process was described by Johnston & DiNardo.[34] We attempt a similar (though not identical) correction, as the last variable in our main models.

While Heckman's original applications of this method focused on selection bias of two states, Lee demonstrated how the same ideas are more generally applicable to multi-state selection bias, using a multinomial logit as the selection function.[35] While no two neighborhoods are identical, the distinction between two neighborhoods of similar design, density and variety of activities may be less important in influencing travel behavior than the distinction between neighborhoods that are vastly different on one or all of these traits; this supports the application of a nominal or ordinal taxonomy on neighborhood form. This taxonomy could then be used in a multinomial logit, and subsequently to estimate an Inverse Mills ratio.

In order to apply such a solution, it is necessary to know the probability and cumulative density functions for multinomial logits. Ben-Akiva and Lerman describe error terms in multinomial logits as Gumbel distributed.[36] So, once a multinomial logit for residential selection is specified, the only remaining matter is to estimate the variables for the related Gumbel (known as location and scale parameters). Those estimates are calculated here using the "gumbel" subroutine for Stata, written by Scotto and Tobias.[37]

Equation 2 describes the residential selection multinomial logit models used here:

(Equation 2) $$\mathbf{R}_{it} = \mathbf{H}\gamma$$

where $\boldsymbol{R_{it}}$ is the conditional probability of a person living in an environment at a particular level of pedestrian accommodation, $\boldsymbol{\gamma}$ is the column vector of regression coefficients, and **H** is the matrix of independent variables made up of the following column vectors:

H_1 = Gender of head of household (1 = Female, 0 = Male)
H_2 = Age of head of household
H_3 = Race of head of household (1 = Non-white, 0 = White)
H_4 = Marital status of head of household (1 = Married, 0 = Non-Married)
H_5 = Presence of handicapped person in household (1 = Yes, 0 = No)
H_6 = Number of persons in household
H_7 = Socio-economic Status Index
H_8 = Number of Full Time Employed persons in household
H_9 = Number of Part Time Employed persons in household
H_{10} = Employment type for Head of Household (1 = white collar, 0 = other)
H_{11} = Percentage of Housing Stock in the Census Block Group built before 1950
H_{12} = Median Rent in the Census Block Group in 1990
H_{13} = Median Housing Value in the Census Block Group in 1990

The multinomial logit allows for the assessment of the utility of selecting into mutually exclusive categories, based on a predetermined reference. In this case, the authors assess the likelihood of selecting into an environment moderately or highly accommodating to pedestrian travel modes, compared to an environment which has low accommodation for pedestrian activity, as defined by a Pedestrian Environmental Factor.[‡,§] Given Weisbrod's findings, two separate models are run for homeowners and renters, respectively; the Inverse Mills estimate for a household selecting their observed pedestrian environment is calculated as described above, then subsequently included in the main model as an endogeneity/self selection adjustment.

Table 1 describes the multinomial model results. The use of traditional socio-demographic variables and housing cost/rent is standard in housing preference models, so their inclusion bears little extended discussion. The calculation of a Socio-Economic Status Indicator (SESI) is a method for getting around limitations of the household income variable in the 1994 Travel Diary data set. The calculation for the SESI attempts to address this loss of variability in the household income measure described earlier by dividing average of the household income category for each respondent by the median household income of the census block group in which the household resides; the authors use this as a more accurate proxy measure of the socio-economic status of the individual household relative to it's immediate neighbors. Similarly, the choice of employment type for head of household is included to reflect the fact that managerial jobs tend to pay higher wages, giving these workers greater latitude in their choice set for residential locations.

Number and type of employed persons and household size is intended to measure the effect of location satisfying behavior, with each household choosing its utility maximizing locale subject to constraints of multi-worker households or the needs of young children to attend school; the greater the number of employees or school age children, the greater the number and intensity of these location constraints. The percentage of surrounding housing stock built before 1950 is taken as an indicator of the degree to which the area in which the household resides is subject to the historical shift in architectural styles as the post World War II housing boom reached full swing, affecting the level of pedestrian facilitation in the neighborhood. Presence of a handicapped individual in the household is included in the model because the transportation needs of disabled individuals may act as a limiting factor in choosing locales that facilitate encumbered movement.

Ben Akiva and Lerman describe one caution of logit modeling, observing that high correlation between model parameter estimates can lead to inefficient model predictions.[35] This situation is most likely to arise when there is high correlation among the independent variables. Table 2 shows the pairwise correlation matrix between the various elements of the multinomial logit described in Table 1. Most elements of the model have fairly low correlations between their values, although size of household does have high correlations with marital status of the head of household and number of full time employed persons in household (.5746 and .4532, respectively).

Table 1A: Multinomial Logit Model for Residential Selection for Home Owners
(Reference Group: Low Pedestrian Accomodating Environment)

	Medium Pedestrian Accomodating Environment		High Pedestrian Accomodating Environment	
	Coefficient	Z	Coefficient	Z
Gender Head of Home (1 = Female)	0.1714	1.40	0.2498	1.29
Age Head of Home	0.0056	1.10	0.0010	0.13
Marital Status of Head of Household (1 = Yes)	-0.1117	-0.67	***-0.4888***	***-1.94***
Race Head of Home (1 = Non-white)	-0.1431	-0.41	0.4731	0.95
Handicap in Home (1 = Yes)	0.0528	0.2	0.1606	0.39
Size of Household	-0.0574	-0.89	-0.1468	-1.44
Socio-Economic Status Index	0.0059	0.07	0.1853	1.66
# FT Employed Persons	-0.1032	-0.99	0.2005	1.16
# PT Employed Persons	-0.0628	-0.45	-0.2026	-0.83
Head of Home Job Type (1 = White Collar)	0.2025	1.37	-0.0660	-0.28
Pct. Homes Older than 1950 - Block Group	**3.5305**	**10.17**	**10.5233**	**22.03**
Median Rent - Block Group	0.0002	0.32	**-0.0028**	**-3.42**
Median Home Value - Block Group	**-1.76E-05**	**-8.25**	**-2.46E-05**	**-7.96**
Constant	-0.0064	-0.01	**-1.5077**	**-2.13**
N				2018
Prob. Chi-Square				0.0000
Pseudo-R^2				0.4015
Log (L)				-1284.86

Table 1B: Multinomial Logit Model for Residential Selection for Home Renters
(Reference Group: Low Pedestrian Accomodating Environment)

	Medium Pedestrian Accomodating Environment		High Pedestrian Accomodating Environment	
	Coefficient	Z	Coefficient	Z
Gender Head of Home (1 = Female)	-0.1576	-0.70	0.2586	0.94
Age Head of Home	0.0058	0.73	**0.0221**	**2.32**
Marital Status of Head of Household (1 = Yes)	-0.2406	-0.74	0.0720	0.18
Race Head of Home (1 = Non-white)	0.6905	1.51	**1.1987**	**2.26**
Handicap in Home (1 = Yes)	-0.0949	-0.17	-0.3623	-0.53
Size of Household	-0.1430	-1.09	-0.2114	-1.28
Socio-Economic Status Index	**0.5909**	**3.09**	0.3515	1.70
# FT Employed Persons	-0.2324	-0.96	0.2944	1.02
# PT Employed Persons	-0.2364	-0.75	0.1855	0.49
Head of Home Job Type (1 = White Collar)	-0.1424	-0.53	-0.3328	-1.01
Pct. Homes Older than 1950 - Block Group	**5.0923**	**8.73**	**9.5274**	**13.38**
Median Rent - Block Group	-0.0016	-1.60	**-0.0057**	**-3.69**
Median Home Value - Block Group	-1.02E-06	-0.47	**-1.10E-05**	**-3.48**
Constant	-0.5432	-0.72	-1.4351	-1.42
N				797
Prob. Chi-Square				0.0000
Pseudo-R^2				0.3511
Log (L)				-564.29

Note: Coefficients in **bold** are significant at the five percent level

Table 2: Correlation Matrix for Independent Variables in Residential Selection Multinomial Logit Model

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
1. Gender Head of Home (1 = Female)	1												
2. Age Head of Home	0.0254	1											
3. Marital Status of Head of Household (1 = Yes)	-0.0368	0.0056	1										
4. Race Head of Home (1 = Non-white)	-0.0328	-0.0305	-0.065	1									
5. Handicap in Home (1 = Yes)	0.042	0.1568	-0.0219	0.0224	1								
6. Size of Household	0.0486	-0.1979	0.5746	0.0119	-0.0159	1							
7. Socio-Economic Status Index	-0.1047	-0.1409	0.2205	-0.0098	-0.083	0.1484	1						
8. # FT Employed Persons	-0.0453	-0.3506	0.406	-0.0295	-0.113	0.4532	0.3234	1					
9. # PT Employed Persons	0.0225	-0.0533	0.1541	-0.0228	-0.0343	0.266	0.0203	-0.1956	1				
10. Head of Home Job Type (1 = White Collar)	-0.0376	-0.3173	-0.0192	-0.0339	-0.1269	0.0393	0.2055	0.3328	0.1773	1			
11. Pct. Homes Older than 1950 - Block Group	-0.0089	-0.0892	-0.1669	0.0364	0.0214	-0.1375	0.1273	-0.0594	-0.0409	0.0454	1		
12. Med.Rent - Block Group	0.0301	0.0509	0.1629	-0.0459	-0.0214	0.1054	-0.1816	0.1026	0.0081	0.0271	-0.2936	1	
13. Med. Hm. Val. - Block Group	-0.0017	0.056	0.0692	-0.0249	-0.0327	-0.0112	-0.1513	0.0071	-0.0107	0.0129	-0.207	0.3856	1

Note: Column heading numbers refer to variables listed in the related row heading (e.g., Column Heading #1 refers to Gender Head of Home; Column heading #2 refers to Age of Head of Home, etc.)

4. Results – Distance Traveled

Table 3 provides a description of urban form impacts on distance traveled, using a Tobit modeling structure. The Tobit is chosen over a standard ordinary least squares (OLS) model because Tobit models are inherently conditional, as described by Johnston & DiNardo;[33] what is the significance of a particular independent variable, or set of variables (in this case, land use measures), given observations meet a particular truncation threshold (i.e., distance traveled greater than zero). This conditional nature allows us to broaden the discussion from just statistical significance and correlation between land use practices and observed distance totals, to an exploration of the significance of land use measures in inducing travel by particular modes. In addition, the Tobit model converges with the standard OLS model estimates of regression parameters as the censoring constraint becomes less applicable.[33]

Looking at the results, both parcel size in the zone and number of intersections within a half mile of the center of the zone where the home is located are significant and consistent with neo-traditional design practices for almost all travel mode categories (although parcel size is insignificant in affecting travel distances for transit and pedestrian modes); the mixed use index is of no significance. Where transit access variables are significant they are mostly consistent with the idea that accessibility to transit (both bus and rail) increases, transit and pedestrian travel distances also increase.

Vehicle access and cost measurements are significant and consistent with expectations for overall travel distances and for vehicle miles traveled (i.e., as variable costs drop and accessibility increases, distance traveled by private vehicle increases), although these same variables had no significant impact on pedestrian distances traveled. The same findings apply for employment status and flexible scheduling. Possession of a driver’s license is significant across the board and consistent with expectations (i.e., promoting greater distances traveled and vehicle distance specifically, while reducing transit and walking distances). With respect to the relevance of socio-demographic variables, the only significant finding was women tend to generate more travel generally (and vehicle miles specifically) than men, that number of children in the household reduces the number of transit miles traveled, and that age resulted in greater automobile distance traveled.[**] Also of interest, the Inverse Mills estimate was statistically significant in explaining travel distances for all categories except walking.

Table 3: Tobit Analysis of Land Use Impacts on Total Miles Traveled per Person, by Travel Mode Type

	Total Miles		Automobile Miles		Transit Miles		Walking Miles	
Variable	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Gender (1 = Female)	**2.4710**	**3.15**	**2.2771**	**2.92**	0.3007	0.16	0.1601	0.53
Race (1 = Non-White)	-0.8384	-0.47	-0.8000	-0.45	-1.8967	-0.45	-0.3874	-0.57
Age	0.1200	0.94	**0.2349**	**2.03**	-0.3517	-1.12	-0.0150	-0.34
Age Squared	-0.0019	-1.42	**-0.0028**	**-2.46**	0.0015	0.43	1.18E-05	0.03
Handicaped (1=Yes)	4.5235	1.41	4.5559	1.46	3.8164	0.51	-1.2364	-1.05
# Children in Household	-0.4708	-1.10	-0.4079	-0.95	***-2.0215***	***-1.90***	-0.2406	-1.41
Employed (1 = Yes)	**5.7618**	**5.00**	**4.8579**	**4.39**	**10.0587**	**3.15**	-0.1112	-0.26
Flex Time (1 = Yes)	**2.6331**	**2.71**	**1.7762**	**1.84**	**5.2097**	**2.38**	-0.5676	-1.48
Income	9.32E-05	1.14	0.0001	0.78	8.89E-05	0.45	-8.76E-06	-0.28
Income Squared	-5.31E-10	-0.76	-3.09E-10	-0.44	-5.09E-10	-0.30	1.05E-10	0.39
Avg. Vehicle Cost	***-0.8947***	***-1.91***	**-1.003501**	**-2.60**	-------------	-------------	-0.2419	-1.60
Transit/Avg. Vehicle Cost Ratio	-8.5422	-0.34	-------------	-------------	-43.5833	-0.76	-------------	-------------
License (1 = Yes)	**9.8188**	**4.53**	**17.7481**	**7.99**	**-26.9261**	**-6.63**	**-2.6997**	**-3.69**
# Vehicles in Household	**2.0034**	**4.43**	**2.4089**	**5.35**	**-6.4747**	**-5.07**	**-0.8695**	**-4.49**
Mult. Phones (1 = Yes)	0.1472	0.13	-0.4705	-0.41	1.6159	0.58	0.5523	1.25
Avg. Parcel Size	**0.1754**	**3.75**	**0.1512**	**3.29**	-0.2349	-1.26	0.0112	0.63
Mixed Use Index	0.0011	0.27	-0.0029	-0.73	-0.0055	-0.55	***0.0025***	***1.79***
Street Intersections	**-0.0190**	**-3.55**	**-0.0190**	**-3.54**	0.0199	1.50	**0.0044**	**2.06**
Total Employment	-0.0003	-0.77	-0.0003	-0.78	0.0003	0.24	***0.0003***	***1.88***
Retail Employment	0.0012	0.73	0.0019	1.20	-0.0061	-1.43	-0.0004	-0.66
Number of Bus Stops	**-0.0506**	**-3.10**	**-0.0504**	**-3.16**	-0.0580	-1.47	**0.0168**	**3.12**
Distance to Bus Stops	**0.0004**	**4.73**	**0.0004**	**5.34**	**-0.0007**	**-2.05**	-3.93E-05	-1.05
Number of Light Rail Stops	**2.8145**	**2.22**	1.0526	0.85	**6.5175**	**2.36**	0.5513	1.27
Distance to Light Rail	**5.45E-05**	**2.49**	**4.61E-05**	**2.11**	6.59E-05	1.18	6.68E-06	0.75
Residential Selection Inverse Mills	**-1.8256**	**-2.25**	**-2.2050**	**-2.72**	***3.6782***	***1.80***	0.3859	1.25
Constant	**17.9037**	**4.02**	6.4003	1.46	-9.4974	-0.95	-2.0995	-1.28
N		3565(3564)		3794(3662)		3950(315)		3771(753)
Likelihood Ratio Chi^2		494.31		576.36		179.9		251.13
Prob. > Chi^2		<0.00005		<0.00005		<0.00005		<0.00005
Log (L)		-16219.849		-16890.389		-2176.2703		-3407.6139
Psuedo R-Squared		0.015		0.0168		0.0397		0.0355

Note: Coefficients in **bold** are significant at the five percent level or greater.
Coefficients in ***bold italics*** are significant at the ten percent level or greater.
'---------------- represents variable not used for this particular regression
1 Numbers in parentheses represent uncensored observations used in the Tobit model

From the results in Table 3, appears the impact of urban design has been validated as neo-traditional design proponents would expect: land use can reduce personal vehicle miles traveled. But this does not necessarily imply walking miles for the same activities are being substituted. To make that argument, one would need to observe both statistical significance, and opposite signs for the same urban form factors in both the vehicle and walking distance models. Looking at the Table 3 model set, this pattern emerges only for street intersections and bus stops. Similarly, the Inverse Mills Ratio acts to suppress distances traveled by motorized modes (and for overall travel), while not significantly promoting walking. So, what to make of this?

At first glance, it would appear proponents of neo-traditional urban design have achieved partial success by reducing vehicle miles. But this might also indicate environments consistent with more pedestrian accommodating designs create situations where vehicle use becomes more difficult, forcing residents and other users of these neighborhoods to curtail vehicle travel. If this reduction in travel results in restrictions on the variety of activities served by travel, the only "success" is to constrain the set of viable travel and activity options. To better understand what is happening, we examine how land use affects consolidation and mode choice for chained trips.

5. Results – Trip Chaining Behavior

The models presented in this section address how urban form alters the number of trips made, both overall and by particular modes? Table 4 relates the number of trip chains completed by particular mode choices to travel behavior and urban form variables. Ordered logits and ordered probits have been used in previous research on individual trip count data by Boarnet to account for the discrete and dominating nature of trips.[6,7,28] For example, it is not possible to make half a trip; a traveler either does or does not complete a transition from an origin to a destination.

Table 4: Ordered Logit Analysis of Land Use Impacts on Number of Chains Generated per Person, by Mode Type

	Total Chains		Auto Based Chains		Transit Based Chains		Walking Based Chains	
Variable	Coef.	Z	Coef.	Z	Coef.	Z	Coef.	Z
Gender (1 = Female)	-0.0858	-1.47	**-0.0987**	**-1.70**	-0.1118	-1.11	0.1188	1.27
Race (1 = Non-White)	-0.1038	-0.78	-0.0961	-0.73	-0.1526	-0.66	-0.0040	-0.02
Age	0.0010	0.10	**0.0189**	**2.18**	-0.0126	-0.71	**-0.0432**	**-3.25**
Age Squared	-8.36E-05	-0.82	**-0.0002**	**-2.08**	-3.27E-05	-0.17	**0.0003**	**2.32**
Handicaped (1=Yes)	-0.0529	-0.21	0.2187	0.92	-0.1609	-0.32	-0.4136	-1.17
# Children in Household	**0.1551**	**4.83**	**0.1902**	**5.96**	**-0.1956**	**-3.28**	0.0317	0.61
Employed (1 = Yes)	-0.0196	-0.22	-0.0989	-1.17	**0.3315**	**2.01**	-0.1759	-1.32
Flex Time (1 = Yes)	0.0360	0.51	-0.0436	-0.61	**0.2402**	**2.09**	0.1439	1.25
Income	1.85E-06	0.30	3.81E-06	0.63	-4.54E-06	-0.43	4.15E-06	0.44
Income Squared	-5.54E-12	-0.11	-2.79E-11	-0.54	9.57E-11	1.06	-5.43E-11	-0.67
Avg. Vehicle Cost	-0.0302	-0.65	0.0051	0.18	--------------	--------------	-0.0120	-0.26
Transit/Avg. Vehicle Cost Ratio	-0.0044	-0.56	--------------	--------------	***0.0142***	***1.69***	--------------	--------------
License (1 = Yes)	**0.9959**	**6.14**	**1.9608**	**11.31**	-0.2890	-1.12	**-1.4490**	**-7.70**
# Vehicles in Household	0.0523	1.53	**0.1665**	**4.88**	**-0.2901**	**-4.46**	**-0.2744**	**-4.53**
Mult. Phones (1 = Yes)	0.1385	1.61	0.0987	1.13	0.1867	1.32	0.1626	1.21
Avg. Parcel Size	-0.0050	-1.35	***-0.0065***	***-1.76***	-0.0031	-0.43	0.0049	0.77
Mixed Use Index	-0.0001	-0.39	**-0.0008**	**-2.84**	0.0002	0.41	0.0006	1.48
Street Intersections	0.0003	0.74	-0.0002	-0.50	0.0008	1.16	**0.0018**	**2.67**
Total Employment	***0.0001***	***1.68***	3.54E-05	1.14	-1.04E-05	-0.20	3.11E-05	0.72
Retail Employment	7.46E-05	0.64	0.0001	1.22	-0.0001	-0.56	0.0001	0.68
Number of Bus Stops	***0.0021***	***1.80***	-0.0006	-0.52	***0.0031***	***1.90***	**0.0049**	**3.38**
Distance to Bus Stops	**-1.18E-05**	**-1.99**	-8.82E-06	-1.53	-1.93E-05	-1.48	-6.36E-07	-0.04
Number of Light Rail Stops	0.0685	0.75	0.0622	0.66	-0.0568	-0.39	-0.0156	-0.13
Distance to Light Rail	**-4.63E-06**	**-2.81**	**-4.93E-06**	**-3.05**	**6.16E-06**	**2.17**	***-5.82E-06***	***-1.87***
Residential Selection Inverse Mills	-0.0983	-1.61	**-0.1552**	**-2.56**	-0.0496	-0.49	**0.2927**	**2.97**
N		3947		3947		3947		3947
Likelihood Ratio		175.6		274.04		123.54		406.65
Prob. > Chi^2		<.00005		<.00005		<.00005		<.00005
Log (L)		-6337.1389		-6679.9919		-1649.0288		-2080.9917
Psuedo R-Squared		0.0137		0.0201		0.0361		0.089

Note: Coefficients in **bold** are significant at the five percent level or greater.
Coefficients in ***bold italics*** are significant at the ten percent level or greater.
'---------------- represents variable not used for this particular regression

Similarly, it is not possible to observe three trips by an individual if they have not made trips one and two. Because trip chains have the same underlying discrete and dominated properties as individual trips, the same modeling techniques are employed here.

The results in Table 4 suggest there is an ability of residential land use patterns to influence both driving and walking chain generation. As in Table 3, driver's license possession and number of vehicles in household had significant effects on trip chains with respect to particular mode types (i.e., promoting vehicle based chains and suppressing pedestrian chains). The significance and sign of these variables support the conclusion the model is theoretically correctly specified. Turning to the impact of land use variables on the total number of trip chains, the urban environment surrounding the home is generally insignificant, except that total trip chains are suppressed by longer distances from the home to transit access points.

When the impact of land uses are separated out by the dominant travel mode for the chain, a new picture emerges. More intersections within a half mile of the center of the zone where the home is located, and increases in the number of bus stops within a half mile of the home all serve to inspire more walking chains. Conversely, larger average parcel sizes and increases in the mixed-use index reduce the number of automobile based trip chains made, while having no significant effect on the number of pedestrian trip chains made. Looking again at the Inverse Mills estimate for the residential environment, the variable is significant in both reducing the number of automobile chains generated, and in increasing the number of walking chains generated.

Table 5: Logit Analysis of Land Use Impacts on Number of Trip Chain Segments per Person, by Mode Type

	Total Number of Chained Trips		Number of Automobile Segments		Number of Transit Segments		Number of Walking Segments	
Variable	Coef.	Z	Coef.	Z	Coef.	Z	Coef.	Z
Gender (1 = Female)	**-0.2178**	**-3.84**	**-0.2304**	**-4.07**	-0.0744	-0.64	0.0273	0.33
Race (1 = Non-White)	-0.0719	-0.55	-0.0688	-0.53	-0.0671	-0.27	-0.1251	-0.69
Age	0.0128	1.38	**0.0283**	**3.38**	-0.0275	-1.50	-0.0168	-1.29
Age Squared	**-0.0002**	**-2.06**	**-0.0003**	**-3.59**	0.0001	0.64	2.10E-05	0.16
Handicaped (1=Yes)	-0.1450	-0.60	0.1106	0.47	-0.1876	-0.43	-0.5297	-1.45
# Children in Household	**0.1008**	**3.22**	**0.1423**	**4.56**	***-0.1255***	***-1.83***	-0.0701	-1.49
Employed (1 = Yes)	0.1387	1.61	0.0279	0.34	**0.6058**	**3.06**	-0.0365	-0.30
Flex Time (1 = Yes)	0.0560	0.81	0.0358	0.51	**0.2859**	**2.16**	0.0336	0.33
Income	-3.08E-06	-0.52	-3.19E-06	-0.54	9.58E-06	0.78	-4.62E-06	-0.54
Income Squared	7.13E-11	1.40	6.63E-11	1.31	-5.25E-11	-0.50	6.26E-11	0.85
Avg. Vehicle Cost	-0.0413	-0.93	-0.0310	-1.10	--------------	--------------	-0.0574	-1.38
Transit/Avg. Vehicle Cost Ratio	-0.0017	-0.23	--------------	--------------	-0.0005	-0.05	--------------	--------------
License (1 = Yes)	**1.1689**	**7.52**	**2.0359**	**11.95**	**-1.7992**	**-8.25**	**-0.6541**	**-3.40**
# Vehicles in Household	-0.0162	-0.49	**0.0825**	**2.50**	**-0.4228**	**-5.20**	**-0.2814**	**-5.23**
Mult. Phones (1 = Yes)	**0.1798**	**2.16**	0.1211	1.43	0.0868	0.51	**0.2356**	**2.00**
Avg. Parcel Size	-0.0037	-1.04	-0.0054	-1.52	-0.0020	-0.24	0.0017	0.28
Mixed Use Index	0.0001	0.35	***-0.0005***	***-1.79***	-0.0003	-0.54	**0.0008**	**2.30**
Street Intersections	0.0002	0.40	-0.0003	-0.76	***0.0014***	***1.66***	**0.0018**	**2.98**
Total Employment	2.18E-05	0.74	1.27E-05	0.42	3.24E-05	0.53	4.15E-05	1.05
Retail Employment	0.0001	0.64	0.0001	0.91	-0.0004	-1.57	0.0001	0.37
Number of Bus Stops	**0.0027**	**2.37**	0.0007	0.57	-0.0035	-1.41	**0.0065**	**4.67**
Distance to Bus Stops	-5.62E-06	-0.98	-5.88E-06	-1.04	-1.95E-05	-0.98	-5.53E-06	-0.49
Number of Light Rail Stops	-0.0546	-0.61	-0.0233	-0.25	**0.3614**	**2.26**	***-0.2103***	***-1.79***
Distance to Light Rail	**-3.60E-06**	**-2.27**	**-3.80E-06**	**-2.42**	-2.17E-06	-0.60	3.43E-07	0.13
Residential Selection Inverse Mills	-0.0069	-0.12	-0.0715	-1.21	**0.2916**	**2.34**	0.1176	1.36
N		3947		3947		3947		3947
Likelihood Ratio Chi^2		240.62		295.78		203.70		352.42
Prob. > Chi^2		<.00005		<.00005		<.00005		<.00005
Log (L)		-10340.1500		-10469.5550		-1592.6519		-3072.2953
Psuedo R-Squared		0.0115		0.0139		0.0601		0.0542

Note: Coefficients in **bold** are significant at the five percent level or greater.
Coefficients in ***bold italics*** are significant at the ten percent level or greater.
'---------------- represents variable not used for this particular regression

Table 5 looks examines the total number of trips per mode type generated as part of individual chains; chain segments are defined as one way, from specific origin to specific destination. The distinction between Table 4 and Table 5 is subtle, but important; the discussion shifts from land use impacts on the generation of touring behavior to an analysis of how land use specifically affects mode choice for trips connected in sequence. Again, license possession and number of vehicles in household behave as anticipated with respect to automobile and pedestrian segments.

While land use appears to have no significant influence on the overall chain length, a very different pattern emerges when one considers the impact on number of links by travel mode. Land use impacts on automobile linkages show weak patterns of statistical significance; higher mixed use indices and increased distance to light rail were significant in suppressing the number of vehicle segments observed, but other than that no significant relationships with land use variables emerged.

With respect to pedestrian linkages, increases in the number of intersections, the mixed use index, the number of bus stops within a half mile of the home, all serve to increase the number of walking linkages made for overall trip making. In contrast, the number of rail stops within a half mile of the home drive down the number of pedestrian linkages made.

The results do not provide any consistent analysis in support or contradiction of the argument that urban form inspires more use of transit. Number of street intersections increases the number of transit segments observed in a particular chain, but this may be confounding the effect of bus stops (which is insignificant). While the residential selection Inverse Mills estimate was significant in explaining the number of transit segments in a particular trip chain, it was not significant in explaining the prevalence of other modes, or for chain length generally.

6. Synthesis of Results

Although from the previous literature there may have been reason to believe that neighborhood scale land use practices could induce travel mode substitutions, the findings supporting those ideas required context. From the models in Table 3, it is apparent that environments more consistent with neo-traditional street designs (i.e., higher intersection density and smaller lot sizes) and improved transit access reduce vehicle distance traveled, while total employment density, mixture of housing and employment and bus transit access work to inspire more walking distance. This is a point in favor of the contention that urban design can reduce vehicle use. Yet the impact of grid like structure on inspiring more walking distance is ambiguous; the greater the degree of grid structure acts to promote walking (as indicated by the positive and significant relationship between total walking distance and the number of street intersections), while the density of that grid structure may have no impact on total distance walked (as indicated by the insignificance of the parcel size variable). Furthermore, distance measures do not speak directly to the optimization of travel behavior in the context of facilitating the activities which travel is supposed to support.

The impacts of land uses on trip chaining behavior by various modes presented in Tables 4 and 5 address this issue of optimization. From Table 4, it appears that decreasing the average parcel size, increases in the mixed use index and enhancing access to bus stops all act to decrease the number of trip chains made by driving. Increasing the number of intersections in the home zone does promote a greater number of walking chains but does not suppress automobile based chains. Table 5 demonstrates that land use practices, on the whole, don't have a significant relationship with regards to generating individual automobile chain segments, though they do appear to generate walking segments as part of chaining behavior.

Of particular interest in Table 3 and Table 4 is the influence of the residential self selection Inverse Mills estimate. Looking at the results by mode type, the pattern appears to be household self selection for preferred residential environment is for minimizing total travel distance regardless of mode (Table 3), though some achieve this by selecting residential locations where goals can be met within walking distance (Table 4). Members of this "walking preferred" group may be less flexible in shifting their mode choice patterns, regardless of urban form modifications, since their initial selection of residential environment was already based on walking as the most efficient method of achieving their goals. Simply modifying the spatial arrangement of their environment would not give them reasons for making additional trips. This explanation is consistent with the general insignificance of the Inverse Mills ratio estimates in Table 5.

7. Conclusion

The purpose of this investigation was to identify and explain how travel mode substitutions, induced by land use patterns consistent with neo-traditional design standards, are expressed in the context of trip chaining for individual travelers. The evidence suggests neo-traditional design elements emphasizing accessibility to goods and services can induce greater walking distances, and number of walking trips as part of existing chains, but do not influence the overall number of trip chains generated. At the same time, neo-traditional land use practices such as street design and transit access reduce total distances traveled (particularly by automobile), but do not reduce the length of trip chains; in fact, the only consistent effect was greater bus access appears to inspire more trip chaining, both in number and length of chains.

The conclusion is that land use substitution effect appears to consolidate trip making and related activities at locations closer to the home, through whatever travel mode is immediately most convenient and/or cost efficient to complete the travel tour, rather than a straight reduction of driving in exchange for more walking behavior. The overall effect in that situation would be to reduce the time and distance from home one would be willing to travel. People walk more in pedestrian supporting/neo-traditional environments, but they still drive when convenient and they are likely doing so over shorter distances. The implication is that local traffic congestion and environmental degradation due to automobile usage may be no better in these neighborhoods than anywhere else. Crane[5,29] suggested this possibility, and the evidence presented here provides empirical support for the position.

These findings also beg the question whether or not local land use practices can be expected to have regional benefit. If the transportation effects of neo-traditional land use are highly localized, the only way to generate wide spread transportation benefits from land use is for multiple small scale interventions. Such coordination would likely require extensive cooperation between local governments, which may or may not view such cooperation as in their individual best interests.

Finally, although the inclusion of the residential selection Inverse Mills estimate helps in making causal statements about land use impacts on travel mode substitution, the issue of environmental selection remains an important issue in its own right. If people are choosing to live in pedestrian accommodating communities, and re-optimizing their travel mode choices and activity patterns accordingly, changes in urban form consistent with neo-traditional design might not, in the long run, achieve changes in individual travel behavior consistent with environmental benefits without the help of supporting policies. Land use practices are best viewed as a complement, not a replacement, for local traffic demand management strategies.

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Figure 1: Overview of Western United States, and Location of Portland Metro Survey Area

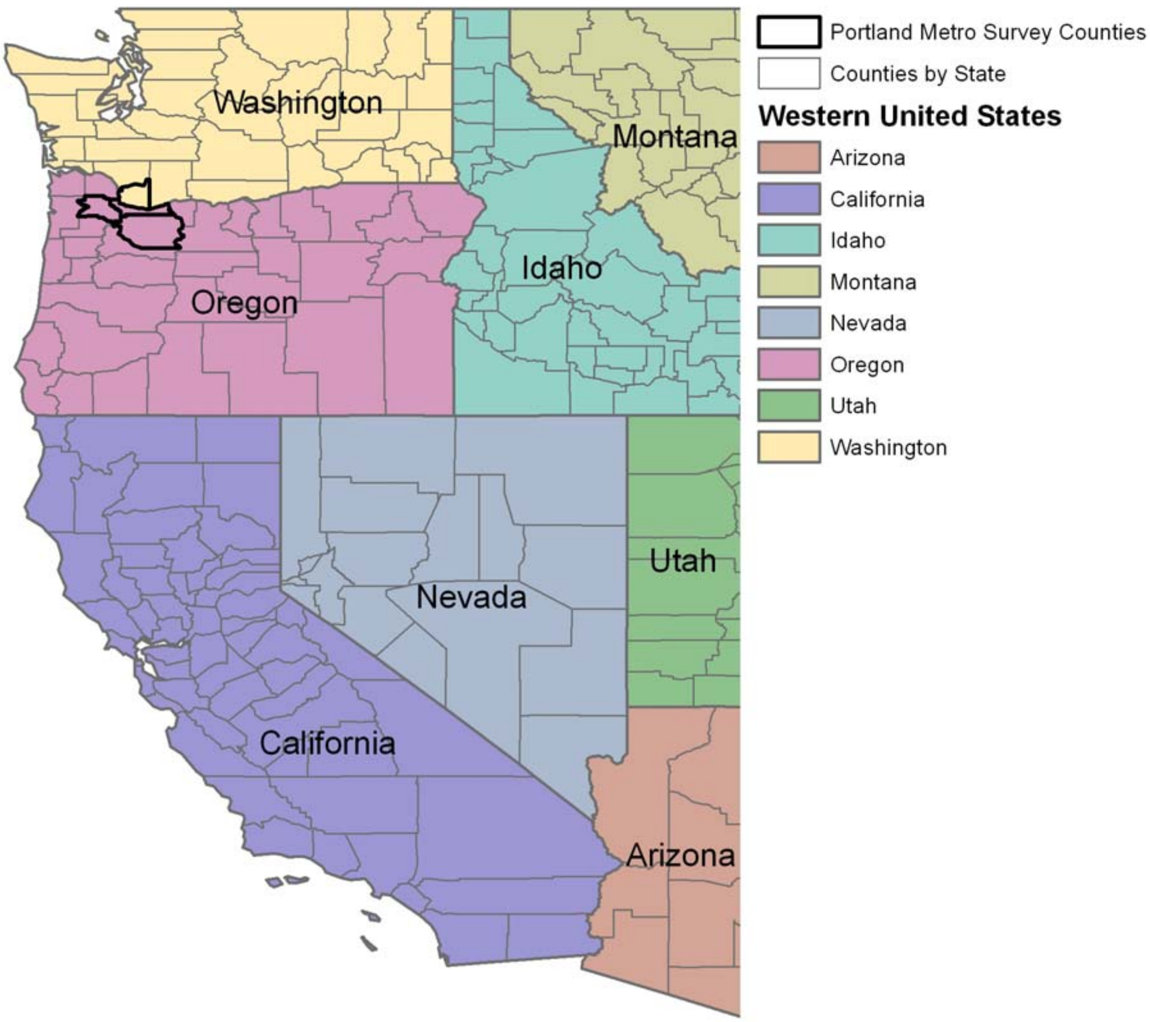
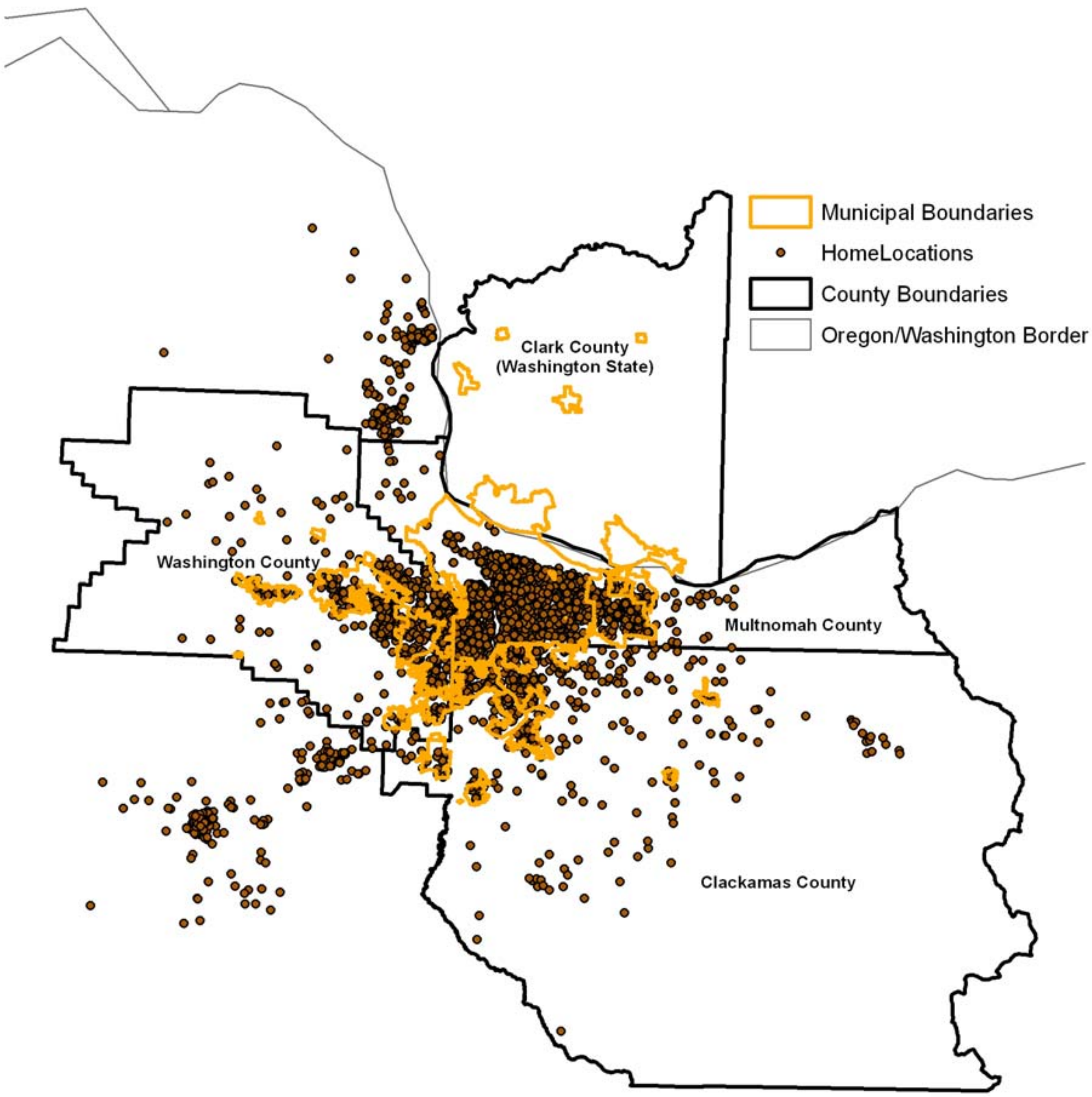


Figure 2: Dispersion of Survey Participant Households Throughout the Portland Metro Region



Endnotes

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[*] Average household vehicle cost was calculated using the vehicle types reported by the 1994 Travel Diary participants, matched to information on fuel efficiency from the U.S. EPA Fuel Economy Database and fuel cost data from the Petroleum Administration for Defense Districts (PADD) weekly average fuel cost data for the five state region including Oregon.[26,27]

[†] Tri-Met changes it's fare structure only once per year, immediately after Labor Day. All individual transit fares were adjusted to reflect any changes in transit fare structure during the survey period, as determined by the survey date of the household.

[‡] For a complete description of the Pedestrian Environmental Factor score, see Cambridge Systems, Inc. et. al. *Making the Land Use Transportation Air Quality Connection, Vol. 4: Model Modifications.* 1000 Friends of Oregon, Portland, 1996.[37] The PEF score was originally developed by a non-profit public interest group known as the 1,000 Friends of Oregon, to indicate the degree to which specific neighborhood areas supported transportation via modes other than individual automobile usage. The score for each zone ranged from four to twelve, a composite of points given for each of four criteria; ease of street crossing, sidewalk continuity, street connectivity (grid vs. cul-de-sac) and topography. Scores for each criteria can range from one to three points. Because the PEF score criteria lend themselves to subjective interpretation, and due to their inherently constrained values, the PEF score is used as an organizing criteria for urban form, in conjunction with home ownership status, as opposed to a direct independent variable.

[§] For the homeowner model developed here, the location parameter value is .07827494 and the scale parameter value is 1.6169474. For the renter model, the location parameter value is .66962923 and the scale parameter value is 1.8699491.

[**] This effect tops out at roughly 42 years old.