

**Assessing the impact of urban form measures on nonwork trip mode choice after
controlling for demographic and level-of-service effects**

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ABSTRACT

The relationship between travel behavior and the local built environment remains far from entirely resolved, despite several research efforts in the area. The current paper investigates the significance and explanatory power of a variety of urban form measures on nonwork activity travel mode choice. The travel data used for analysis is the 1995 Portland Metropolitan Activity Survey conducted by Portland Metro. The database on the local built environment was developed by Song (2002) and includes a more extensive set of variables than previous studies that have examined the relationship between travel behavior and the local built environment using the Portland data. The results of the multinomial logit mode choice model indicate that mixed-uses promote walking behavior for nonwork activities.

1. INTRODUCTION

The increasingly adverse effects of automobile use on traffic congestion and air pollution, combined with the limited financial ability of states to continually invest in transportation infrastructure, has led to the consideration of land use strategies for managing and influencing travel demand. The paradigm shift toward land use strategies to manage travel demand gained momentum, in particular, with the advent of the New Urbanism movement in the early 1990s (1). The New Urbanism movement is a manifestation of environmental determinism, wherein the urban planner's role is to engineer and encourage socially vibrant communities and environmentally friendly modes of transportation such as walking and bicycling. Proponents of this movement assert that design principles modeled on pre-WWII communities can reduce automobile dependence.

The consideration of land use strategies to manage demand, spurred by the New Urbanism movement as well as air quality regulations and, more recently, efforts to increase physical activity in order to improve public health, has led to a recent burgeoning in the literature at the interface of land use and transportation. Numerous studies in the past decade focused on the influence of urban form and the built environment on travel behavior. While these studies have contributed substantially to our understanding of the interactions between urban form and travel behavior, considerable research remains to be done in this area. The next few sections discuss some of the issues characterizing earlier studies, and position the current study in the broader context of the earlier studies.

1.1 Work versus Nonwork Travel Mode Choice

The association between aspects of the built environment at the employment site or residence and workers' commute choices has been studied by many researchers [for example, see Cervero (2,3); Cambridge Systematics (4); Kockelman (5); Messenger and Ewing (6); Cervero and Wu (7); Levinson and Kumar (8)]. In contrast to the focus on the effect of the built environment on commute travel, there has been relatively lesser attention on the influence of the built environment on nonwork travel [for example, see Handy (9); Bhat et al. (10); Boarnet and Sarmiento (11); Boarnet and Crane (12); Reilly (13)]. Nonwork trips constitute about three-quarters of urban trips and represent an increasingly large proportion of peak period trips (14). In addition, non-work trips are generally more flexible than work trips and thus may be influenced by urban form to a greater degree than are work trips. For these reasons, it is important to analyze the impact of land use on nonwork travel. This study contributes toward this objective by examining the impact of the built environment on nonwork mode choice. The focus on the modal dimension of nonwork trips is motivated by the observation that the few earlier studies examining land use impact on nonwork travel have not focused on this dimension [for example, Handy examines land use impacts on shopping trip frequency (9); Bhat et al. study land use and other variable impacts on shopping trips (10); Boarnet and Sarmiento and Boarnet and Crane examine land use impacts on nonwork automobile trips (11, 12)]. Reilly's study is the closest to the current research paper, although the empirical settings are different between his paper and ours (13). In addition, Reilly uses qualitative measures such as a Transit Access Index and proxies for streetscape in his San Francisco study, while the current paper attempts to use more direct measures of urban form (13).

1.2 Urban Form Measures

Earlier research studies have used various kinds of urban form measures to capture the effect of the built environment on travel behavior. But in any particular study, it has been quite typical to consider only a handful of measures of urban form (and in most cases, just one measure). For example, a single measure of density has been used in several studies including Bhat and Singh (15), Spillar and Rutherford (16) and Dunphy and Fisher (17). Some other studies such as Cervero et al. (18), Handy (19), Bhat and Pozsgay (20), and Bhat and Zhao (21) have focused on a single measure of accessibility to study the effect of urban form on travel and related behavior. A handful of studies have considered multiple urban form measures jointly. These multiple measures have typically been one of the two composite urban form measures discussed earlier (density or accessibility) and one or two additional characteristics of urban form. For instance, Frank and Pivo (22) consider density and land use mix, Holtzclaw (23) and Kitamura et al. (24) use density and an accessibility measure, Kockelman (25) considers accessibility, land use mix, and land use balance, Greenwald and Boarnet (26) use a composite pedestrian environment factor, population and retail densities, and proportion of gridiron streets, and Handy and Clifton (27) use distance from home to shopping as well as perceptions about the quality of the walking environment.

In this study, the focus is on capturing a multitude of urban form measures, some of which are composite indices (such as land use mix and accessibility) and others of which are direct, disaggregate measures of the built environment. Thus, for example, we consider not only the degree of mixing of different land uses, but also consider the actual kinds of land uses involved in the mixing. Hess et al. (28) note that capturing the degree of mix may not suffice, and recommend including the actual kinds of land uses. Additionally, we examine the influence of the built environment, while controlling for the effects of sociodemographic and level-of-service variables on travel behavior.

1.3 Scale of Measurement and Level of Analysis

The studies of land use and travel behavior may use urban form measures based on spatially aggregate units (such as city-level or urban/suburban level) or on much more disaggregate spatial units (such as the neighborhood level). Similarly, the analysis may be conducted at the level of an aggregate group of individuals or at the individual level. Therefore, four combinations of geographic scale and level of analysis are possible: (a) aggregate spatial data and aggregate sociodemographics [for example, see San Diego Association of Governments (29); Handy (19); Holtzclaw (23); Parsons Brinckerhoff Quade Douglas (30); McNally and Kulkarni (31)], (b) aggregate spatial data and disaggregate sociodemographics [for example, see Schimek (32); Kockelman (25); Boarnet and Crane (12); Greenwald and Boarnet (26)], (c) disaggregate spatial data and aggregate sociodemographics, and (d) disaggregate spatial data and disaggregate sociodemographics [for example, see Cervero (3); Kitamura et al. (33); Handy and Clifton (27); and Reilly (13)].

As should be obvious from above, there have been few studies that have employed urban form measures at a high level of spatial resolution and conducted the analysis at an individual level. In this paper, we use a GIS-based method to develop urban form measures at the neighborhood level of each household and conduct the analysis at an individual level.

1.4 Summary and Overview of Current Research

This paper examines the impact of the built environment on travel behavior, with specific focus on nonwork travel. The analysis presented here uses a multitude of urban form measures, including composite indices and direct disaggregate measures. The analysis in the paper is based on a high spatial resolution for developing measures of urban form and is performed at the level of the decision-making unit (*i.e.* the individual tripmaker) and. A discrete choice methodology is used to examine the effect of household and individual sociodemographics, level-of-service of travel modes, and urban form measures on nonwork travel mode choice. The primary data source used for this study is the 1995 Portland Metropolitan Area Activity Survey, which collected travel information from members of a sample of households over a two-weekday period.

The rest of this paper is organized as follows. The next section describes the data sources and the sample formation process. Section 3 discusses model specification issues. Section 4 presents the results of the empirical analysis. Finally, Section 5 summarizes the significant findings from the research and identifies areas for future work.

2. DATA ASSEMBLY

2.1 Data Sources

The primary source used in this study is the Portland Metropolitan Area Activity Survey conducted by Portland Metro in the Spring and Fall of 1995. This survey was a two-weekday travel diary of households. The information gathered in the activity survey included the travel mode used, start and end time of the trip and the activity, origin and destination locations (which were later mapped to traffic analysis zones) and individual and household socio-demographic information.

In addition to the primary data source, three secondary data sources were used to generate the final sample for analysis. First, we used a zone-to-zone level-of-service file that includes mode-specific travel times and costs between each pair of zones in the Portland metropolitan region. This data includes a zone-to-zone transit fare matrix, and parking charges in each destination zone (besides the inter-zonal travel times by auto and transit). Travel times for the walk and bicycle modes are generated for each zonal pair based on the network distances and assuming an average walking and bicycling speed of 3 miles/hour and 10 miles/hour respectively, as suggested by Portland Metro. Walk and bike modes are assumed to entail no monetary cost to the trip maker. Second, we used a zone-level land use file obtained from Portland Metro that provides the retail employment at each traffic analysis zone. The first and second data sources are used to develop a composite measure of accessibility to nonwork activity destinations for each travel mode and each zone. Third, we used a neighborhood-level land use Geographic Information System (GIS) shape file developed by Portland Metro and enhanced by Song (34) (to include several urban design and land use measures). This spatial land use file provides the following information for Washington County: (a) neighborhood land area, (b) area dedicated to each use (single-family housing, multi-family housing, commercial, industrial, and public open spaces), (c) population and housing unit densities in each neighborhood [developed by Song (34)], and (d) local street network characteristics [number of blocks per housing unit, length of linear street network, fraction of cul-de-sac streets, street connectivity index *etc.* developed by Song (34)]. The definition of “neighborhood” adopted by Portland Metro is synonymous with census block group boundaries, except when an arterial road cuts across

census block groups; in which case the block group is further divided with the arterial road representing a boundary.

2.2 Sample Formation

The process of developing the sample involved several steps. First, the composite (travel and non-travel) activity file was converted into a corresponding trip file. In doing so, information on the type of activity pursued at, and the zone identifier for, the origin and destination ends of each trip were retained. Second, nonwork trips originating at home were selected from the trip file based on the activity type designations at each end of the trip. Third, the travel mode chosen for each trip was identified and assigned one of the following categories: drive-alone, shared-ride, transit, walk, and bike. Fourth, the availability of modes for each trip was determined as follows: (a) Driving alone is considered as being available if the individual making the trip has a vehicle in the household and is a licensed driver, (b) Ridesharing is designated as being available to all individuals in the sample, (c) Transit is designated as being available to individuals whose origin-destination zonal pair has existing bus routes (this information was provided by Portland Metro), (d) Walking is designated as being available to individuals whose trip distance is less than the maximum distance walked by an individual in the sample, and (e) Biking is designated as being available to individuals whose trip distance is less than the maximum distance biked by an individual in the sample. Fifth, the trip data were matched with the appropriate sociodemographic characteristics of the individual pursuing the trip and his/her household. Sixth, the mode-specific level-of-service data were appended to each record based on the origin-destination zones and time-of-day of the trip. Seventh, the zone-level composite accessibility measures were matched with each trip record based on the origin zone. This provides the overall accessibility by each mode from the home zone of the individual pursuing the trip. Eighth, the location of the household of each traveler's trip was geocoded, using the ArcGIS spatial tool, to the neighborhood level at which the urban form measures are available. This enables the assignment of urban form measures associated with the residence of the individual to each nonwork trip pursued by the individual. Since the urban form measures were available only for Washington County, the final trip sample includes only the trips of individuals residing in this county.

The final sample for analysis includes 2,500 individual home-based¹ nonwork trips (originating from 369 different households in 131 neighborhoods in Washington County), out of which 706 are shopping trips, and 763 are recreational trips. The overall mode shares for nonwork trips are as follows: drive-alone (48.1%), shared-ride (42.4%), transit (2.7%), walk (5.7%), and bicycle (1.1%).

3. EMPIRICAL ANALYSIS

3.1 Model Variables

We considered four sets of variables for inclusion – household sociodemographics, individual sociodemographics, trip characteristics, and urban form measures.

¹ Home-based trips, for the purpose of this study, refer to trips that originate at home; *i.e.* trips that have the tripmaker's residential zone as the origin TAZ.

3.1.1 Household Sociodemographic Characteristics

The household sociodemographic attributes considered in our analysis included household income, number of vehicles per adult (above the age of 16) in the household, and number of children (below the age of 16) in the household.

3.1.2 Individual Sociodemographic Characteristics

The individual sociodemographic characteristics that were explored included sex and age of the individual, ethnicity, student status, presence of a physical handicap and employment status.

3.1.3 Trip Characteristics

The trip characteristics represent level-of-service variables. The in-vehicle travel time and out-of-vehicle travel time variables were combined into a single time variable, as initial testing of specifications rejected that their effects were different. Separate time coefficients were estimated for motorized and non-motorized modes to accommodate the differential time sensitivities based on travel mode. Travel cost was also included in the group of level-of-service variables.

3.1.4 Urban Form Measures

The urban form measures incorporated in the model belonged to four categories: land use type and mix, accessibility, residential density, and local street network. The next four paragraphs discuss each of these categories in greater detail.

The first category of urban form measures comprises the distribution quotients and a land use mix diversity variable. The distribution quotients are ratios of acreage in each land use type to the number of housing units in the neighborhood [see Bendavid-Val (35) for use of distribution quotients]. These ratios have been incorporated to overcome Hess et al.'s (28) critique that land use-travel behavior models fail to test the effect of the types of uses mixed. The degree of land use mix is captured by the land use mix diversity measure. This measure varies between 0 and 1 and has been computed as follows [see Bhat and Gossen (36) who propose such a measure]:

$$\text{Land use mix diversity} = 1 - \left\{ \frac{\left| \frac{r}{T} - \frac{1}{4} \right| + \left| \frac{c}{T} - \frac{1}{4} \right| + \left| \frac{i}{T} - \frac{1}{4} \right| + \left| \frac{o}{T} - \frac{1}{4} \right|}{\frac{3}{2}} \right\} \quad (1)$$

where r = acres in residential use (single and multi-family housing), c = acres in commercial use, i = acres in industrial use, o = acres in other land uses, and $T = r + c + i + o$. A value of 0 for this measure means that the land in the neighborhood is exclusively dedicated to a single use, while a value of 1 indicates perfect mixing of the four land uses.

The second category of urban form measures represents accessibility variables. Three accessibility variables are considered in the analysis: accessibility index, percentage of households within walking distance from commercial establishments, and percentage of households within walking distance from bus stops. While the first measure is an indicator of regional accessibility, the other two measures are associated with local accessibility [see Handy (19)]. The accessibility index has been computed using Levinson and Kumar's (37) gravity-type functional form as follows:

$$A_{im} = \sum_{j=1}^J [f(C_{ijm}) * R_j] \quad (2)$$

where $f(C_{ijm})$ is the friction factor between zones i and j by mode m [computed using the same functional form as used in Levinson and Kumar (37)], R_j is the retail employment in zone j , J is the total number of zones in the Portland metropolitan area, i is the zone for which the accessibility index is being computed, and m is the mode for which the accessibility index is being computed

Residential density is the next land use variable included in the model specification. It is defined as the population per unit area of a neighborhood [see Song (34) for development of this measure]. Density has often been used to proxy a large number of excluded urban form measures. By including the residential density measure alongside other land use characteristics, this paper attempts to isolate the “true” impact of density.

Finally, the local street network variables [developed by Song (34)] capture the suitability of neighborhood streets for pedestrian and bicycle use. This set of variables includes a connectivity index and the percentage of cul-de-sac streets in the neighborhood. The connectivity index is defined as the ratio of the number of links to the number of nodes in the neighborhood. A greater value of this measure indicates a larger number of routes available for a given pair of point locations. Cul-de-sacs are common features of post World War-II type developments and are often considered the converse of traditional grid-like street geometry.

The final model specification was developed through a systematic process of adding variables to the constants-only model, eliminating statistically insignificant variables, and combining statistically similar variables. This process was guided by intuitive reasoning and parsimony in the representation of variable effects.

3.2 Estimation Results

The results of the multinomial logit estimation of the final model specification are presented in Table 1. The closed form of the MNL makes it straightforward to estimate, interpret, and use. The parameter estimates in the MNL model indicate the effects of exogenous variables on the latent utilities of the four modes relative to the shared-ride alternative. The shared-ride alternative was found to be the most convenient base alternative since it was the only mode available to every individual in the sample.

The log-likelihood value at convergence of the market share model is -2067.1 , while the log-likelihood value of the final model specification is -1798.45 . The likelihood ratio test value to compare the final model with the market share model is 537.3 , which exceeds the critical chi-square value corresponding to 34 degrees of freedom at any reasonable level of significance. Thus, the hypothesis of no observed variable effects is rejected.

In the subsequent sections, we present and explain the effects of variables, considering one set of variables at a time. The variables have been included with the coefficient on the shared-ride mode as the base. Three sets of constants are estimated, one for non-shopping and non-recreational trips, another for shopping trips, and a third for recreational trips. This is done to accommodate mode share differences across trip purposes.

3.2.1 Household Sociodemographic Characteristics

Among the household sociodemographic variables, the annual household income was tested for a quadratic effect [see Boarnet and Sarmiento (11) and Boarnet and Crane (12)]. The results indicate that households below the income level of \$50,652 per annum derive diminishing

benefits from driving alone with an increase in income. On the other hand, individuals from higher-income households tend to drive more as their income rises. In other words, carpooling, riding transit, walking and biking are more attractive options relative to driving for households in the middle-income category. This may be a reflection of the increased availability of time for households that are rising from the lower-income to the middle-income category, which can be spent on a leisurely stroll in the park or on a social visit. Higher-income households, on the contrary, may have stringent time constraints and so prefer faster modes.

An increase in the number of vehicles per adult in the household significantly increases the likelihood of choosing to drive-alone, as one would expect. The results also indicate that non-motorized modes are particularly unlikely to be used as vehicle availability increases. The next household characteristic is the number of children present in the household. A household with a higher number of children (persons below 16 years of age) is more likely to rideshare, as indicated by the negative and statistically significant coefficient for non-rideshare modes. This is a reflection of the mobility dependence of children on the adults in the household.

Finally, in the category of household sociodemographics, the effect of the number of adults indicates a lower propensity to walk for individuals with several adults in the household. Further exploration of this effect is an area for future study.

3.2.2 Individual Sociodemographic Attributes

In the class of individual sociodemographics, age has a significant impact on mode utilities. Non-linear effects were explored in our analysis, but the simple linear representation performed as well as non-linear forms. The magnitudes of the coefficients on age indicate that older individuals most prefer to rideshare for their non-work trips. This may reflect fewer time constraints among older individuals, and the consequent use of nonwork trips as socializing opportunities.

The impacts of other individual sociodemographic traits indicate that physically handicapped individuals are more likely to travel by non drive-alone modes, and Caucasians have a greater aversion to walking than individuals from other ethnic backgrounds [see Greenwald and Boarnet (26) for similar results].

3.2.3 Level-of-Service Variables

The model estimation results indicate the usual negative impacts of travel time and travel cost. The results indicate that an additional minute of walk or bike time is marginally more onerous than a minute of driving or transit time. The implied money values of travel time by motorized and non-motorized modes are \$16.19 per hour and \$18.91 per hour, respectively. It is indeed interesting to note the similarity in valuation of travel time across modes.

3.2.4 Urban Form Measures

As indicated earlier, four subgroups of urban form measures were considered in the current analysis. The effects of urban form measures are discussed by subgroup below.

In the subgroup of land use type and mix, the effect of the ratio of park area per housing unit indicates, as expected, that availability of parks in the neighborhood increases the propensity to walk for recreation. The coefficient on the land use mix diversity index specific to transit is not significant, indicating that the impacts of transit-oriented development on transit ridership may be limited. On the other hand, the positive coefficient specific to the walk mode indicates that mixed-uses have the potential to substitute the use of motorized travel modes with the walk

mode. Overall, the effect of the land use mix diversity index corroborates the effectiveness of mixed-uses in encouraging walking as a mode for nonwork travel.

The results of the accessibility index indicate that residents of a zone with higher regional accessibility by a given mode have a greater preference for recreational trips for that mode. The coefficient on the percentage of households within walking distance from bus stops (a measure of local accessibility) indicates a higher propensity to ride transit for individuals who live close to bus stops. Although this finding is consistent with New Urbanist concepts, the possibility of self-selection into transit-oriented neighborhoods cannot be discounted.

The results of the impacts of residential density (captured by population density) indicate that denser neighborhoods decrease the likelihood of driving alone and increase the likelihood of transit use. However, this latter effect is rather insignificant, primarily because of the high degree of correlation between the “percentage of households within walk distance from bus stops” and the residential density variable.

The final variable in Table 1 is the percentage of cul-de-sacs. The direction of the influence of cul-de-sac streets is intuitive. A large number of cul-de-sac streets in a neighborhood (reminiscent of post World War-II type developments) might make walking difficult because of curvilinear and seemingly longer routes.

4. POLICY IMPLICATIONS

The results of the multinomial logit mode choice model have several important policy implications [see Ben-Akiva and Lerman (38) for a description of the model structure]. The aggregate-level elasticity effects of variables are often used to assess the potential impacts of policy actions. In the following sections, the computation procedure for elasticity effects is explained and their implications are discussed.

4.1 Computation of Elasticity Effects

The self and cross elasticity effects of mode-related variables like travel time and the accessibility index have been computed using the standard multinomial logit formulations.

The aggregate-level elasticity effect of a continuous exogenous variable such as age may be computed by weighting the disaggregate-level elasticities by mode choice probabilities. The disaggregate-level elasticities with respect to variables with linear effects (*e.g.* age, land use mix diversity index, cul-de-sacs) may be computed as follows:

$$E_{x_k}^{P_n(i)} = x_k [\gamma_{ki} - \sum_j P_n(i) \gamma_{kj}] \quad (3)$$

where x_k is the k^{th} attribute, $P_n(i)$ is the probability that individual n chooses alternative i , and γ_k is the parameter estimate for the k^{th} attribute specific to the j^{th} alternative.

The aggregate-level elasticity is then computed as follows:

$$\eta_{x_k}^{P(i)} = \frac{\sum_{n=1}^N P_n(i) E_{x_k}^{P_n(i)}}{\sum_{n=1}^N P_n(i)} \quad (4)$$

To compute an aggregate-level elasticity of an ordinal exogenous variable (such as the number of children in the household), we increase the value of the variable by 1 unit for each observation and compute new mode shares. We then compute the aggregate-level elasticity as follows:

$$E_{x_k}^{S(i)} = \frac{S'(i) - S(i)}{S(i)} \quad (5)$$

where $S(i)$ and $S'(i)$ are the shares of alternative i before and after the ordinal variable is increased by 1 unit respectively.

Finally, to compute the aggregate-level elasticity of a dummy exogenous variable (such as ethnic status, and presence of a handicap), we divide the entire sample into two subsamples based on the value of the dummy variable. We then compute shifts in mode shares in each subsample due to a zero to one and one to zero change in the dummy variable respectively. The ratio of the difference of the shifts between the two subsamples to the aggregate mode shares in the entire sample yields the aggregate-level elasticity of the dummy variable.

4.2 Elasticity Effects of Exogenous Variables

Table 2 presents the elasticity effects of all statistically significant non-mode related exogenous variables. The elasticity values indicate that vehicle ownership has a substantial impact on mode choice decision-making. Among individual sociodemographic characteristics, ethnicity (whether the individual is Caucasian or not) is the single most important determinant of the likelihood to walk. Although urban form measures do not seem as critical to mode choice, there are some important implications for integrated transportation-land use modeling. First, mixed-uses lead to considerable substitution between motorized modes and walk modes. However, its influence on transit is quite contrary to expectation. Third, higher densities considerably improve the chances of walking as compared to other modes. Fourth, cul-de-sacs, characteristic of planned unit developments (PUD), can increase the resistance to walking and lead to greater automobile dependence.

Table 3 presents the self and cross elasticity effects of mode-related variables. The self-elasticity results indicate that the share of walking (transit) for nonwork trips is very sensitive to increases in walk time (transit time). On the other hand, drive-alone share is relatively insensitive to travel time and cost increases associated with the private automobile. Further, the self-elasticity values show a substantial increase in the walk/bicycle share for recreational trips due to an improvement in accessibility by the walk/bicycle modes. This reinforces the idea that individuals prefer to walk or bike to accessible destinations for recreational purposes. Thus, providing a safe and comfortable pedestrian/bicycle environment, along with bringing shopping and recreational activity sites closer to residential neighborhoods, may be an effective way to reduce automobile dependency. However, another issue that deserves attention is the high cross-elasticity between the walk and bicycle modes associated with accessibility (see the last two rows in Table 3). That is, improvement in walk (bicycle) accessibility draws most shares away from bicycle (walk) modes. This suggests that it is important to improve both the accessibilities by bicycle and walk modes simultaneously to increase non-motorized mode share.

5. CONCLUSIONS

This paper presents a multinomial logit mode choice model for nonwork activity travel. The choice set comprises drive-alone, shared-ride, transit, walk and bike. The motivating factors for this study are: (a) the growing proportion of nonwork travel, and (b) the desire to explore the urban form influence on mode choice. The empirical analysis in this paper is based on the 1995 Portland Metropolitan Area Activity Survey. The model specifications tested several variables describing household sociodemographics, individual demographics, level-of-service variables and land use characteristics such as land use mix, accessibility, residential density and cul-de-sacs. Some salient results of the analysis are as follows:

- Individuals in higher-income households have a greater tendency to drive-alone to nonwork activity sites as compared to individuals in lower-income households. However, there is no difference in their propensity to choose among other modes. Likewise, individuals in households that own more vehicles are more likely to drive-alone and less likely to walk or bike as compared to individuals in households owning fewer vehicles. Further, households with a large number of children are more likely to rideshare, because of the mobility dependence of children.
- Older individuals tend to carpool or vanpool more and ride transit less than younger individuals for nonwork travel, while physically challenged individuals are less likely to drive and Caucasians are less likely to walk, for nonwork travel.
- People tend to value walk and bike time only marginally more than they value travel time by motorized modes.
- Mixed-uses and higher residential densities encourage walking and transit mode for nonwork travel, while a large number of cul-de-sacs in local streets discourage walking. An increase in regional accessibility has the greatest positive influence on the propensity to walk/bike for recreation.

The results indicate a clear relationship between mode choice decision-making for nonwork activity travel and urban form characteristics. Most notably, mixed-use neighborhoods are associated with increased walking, thus suggesting that an improvement in the diversity of uses in neighborhoods through flexible zoning can reduce automobile dependence. Our exploration of accessibility measures yield results consistent with previous studies. If destinations are easily accessible by walk/bicycle, people are more likely to walk/bike for recreational activities. Appropriate urban design may thus prove an effective strategy for making walking and biking more attractive. Our empirical analysis also suggests that traditional neighborhood street design with few cul-de-sacs and a grid-like geometry has the potential to encourage walking [see Handy (9) for a similar result about frequency of walking trips]. However, various other factors such as street landscape and safety of sidewalks must be analyzed in conjunction with street geometry.

The current study may be extended in a number of ways. First, modeling mode choice and residential location choice decisions jointly would aid in disentangling the “true” causal effect of urban form on mode choice from the “spurious” effect of individuals selecting neighborhoods that support their intrinsic mode choice preferences. Second, panel data would enable a longitudinal study rather than a cross-sectional study, thereby strengthening the analysis of causal relationships.. Unfortunately, panel data are not available for Portland at this time. Third, since much of nonwork travel occurs during the weekend, data on weekend travel would facilitate a more comprehensive examination of the effect of the built environment on nonwork travel. Finally, the inclusion of additional variables that reflect characteristics of both the built environment and the natural environment might improve the explanatory power of the models.

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TABLE 1 Effect of Exogenous Variables on Mode Choice

Variable	Drive-alone		Transit		Walk		Bike	
	Parameter	t-statistic	Parameter	t-statistic	Parameter	t-statistic	Parameter	t-statistic
Constants								
Non-work trips	1.1326	2.9288	0.8171	1.9937	4.1932	5.6167	-0.1435	-0.2777
Shopping	1.2208	0.7335	-0.9392	-3.6452	3.1303	-2.6117	-0.1435	-0.2777
Recreation	0.6571	-3.8603	-1.6597	-3.9041	4.8778	1.8767	-0.0066	0.2451
Household Sociodemographics								
Income in 10,000 dollars	-0.3728	-2.8501						
Square of Income	0.0368	2.8058						
Vehicles per adult	0.7728	4.7186			-1.3678	-4.2016	-1.3678	-4.2016
Number of kids (<16 years)	-0.3847	-7.7692	-0.3847	-7.7692	-0.3847	-7.7692	-0.3847	-7.7692
Number of Adults					-0.6012	-3.8751		
Individual Sociodemographics								
Age	-0.0106	-3.3650	-0.0651	-6.7885	-0.0148	-3.4140	-0.0557	-3.5954
Handicap dummy	-1.1981	-2.3358						
Caucasian dummy					-1.0711	-2.7444		
Trip Characteristics								
Total Travel time in minutes	-0.0447	-5.0975	-0.0447	-5.0975	-0.0542	-9.4514	-0.0542	-9.4514
Travel cost in dollars	-0.1657	-1.5668	-0.1657	-1.5668	-0.1657	-1.5668	-0.1657	-1.5668
Urban Form Measures								
Park area per housing unit (recreational trips)					0.0001	1.5404		
Land-use Mix Diversity Index					1.1097	2.3827		
Natural Log of Accessibility Index (recreational trips)	0.1205	1.3466	0.1205	1.3466	0.1205	1.3466	0.1205	1.3466
Percentage of households within walking distance of bus stops			1.1863	1.9907				
Population density	-0.0202	-1.0898	0.0289	0.4381				
Percentage of cul-de-sac streets					-0.9802	-3.0136		
Percentage of cul-de-sac streets (shopping trips)					1.5592	3.2482		

TABLE 2 Aggregate Level Elasticity Effects of Non-Mode Related Exogenous Variables on Mode Shares

Variable	Drive-alone	Shared-ride	Transit	Walk	Bike
Household Sociodemographics					
Annual Household Income (in 10,000 dollars)	0.1232	-0.0718	-0.0295	-0.0381	-0.0346
Vehicles per Adult	0.4125	-0.1324	0.0444	-1.0464	-1.0617
Number of Kids (<16 years)	-0.1647	0.1467	-0.2104	-0.1687	-0.2078
Number of Adults (>=16 years)	0.0226	0.0385	0.0622	-0.3462	0.1156
Individual Sociodemographic Characteristics					
Age in years	-0.1895	0.1957	-0.7040	-0.2621	-0.8292
Handicap Dummy	-0.8834	0.4968	0.3044	0.4264	0.2877
Caucasian Race Dummy	0.0678	0.1319	0.3037	-1.8725	0.4499
Urban Form Measures					
Park Area per housing unit (recreational trips)	-0.0063	-0.0101	-0.0120	0.0871	-0.0219
Land Use Mix Diversity Index (all non-work trips)	-0.0179	-0.0269	-0.0370	0.3610	-0.0785
Percentage of Households within walking distance from bus stops (all non-work trips)	-0.0041	-0.0166	0.4177	-0.0169	-0.0361
Population density (all non-work trips)	-0.0309	0.0145	0.0775	0.0096	0.0009
Cul-de-sac streets (all non-work trips)	0.0002	0.0004	0.0004	-0.0046	0.0001

TABLE 3 Aggregate Level Self and Cross-Elasticity Effects of Mode-Related Variables

	Drive-alone	Shared-ride	Transit	Walk	Bike
Total Travel Time					
Drive-alone	-0.0729	0.0684	0.0682	0.0508	0.0674
Shared-ride	0.0604	-0.0819	0.0574	0.0489	0.0624
Transit	0.0104	0.0097	-0.8689	0.0080	0.0167
Walk	0.0857	0.0939	0.0782	-0.8655	0.1397
Bike	0.0022	0.0023	0.0035	0.0025	-0.3996
Travel Cost					
Drive-alone	-0.0171	0.0147	0.0210	0.0170	0.0151
Shared-ride	0.0065	-0.0099	0.0116	0.0096	0.0080
Transit	0.0014	0.0013	-0.1142	0.0011	0.0022
Walk	-	-	-	-	-
Bike	-	-	-	-	-
Natural log of accessibility (recreational trips)					
Drive-alone	0.1242	-0.1091	-0.0289	-0.1295	-0.1265
Shared-ride	-0.0967	0.1477	-0.0291	-0.1568	-0.1471
Transit	-0.0005	-0.0006	0.0525	-0.0011	-0.0014
Walk	-0.0163	-0.0218	-0.0072	0.1814	-0.0330
Bike	-0.0014	-0.0018	-0.0008	-0.0031	0.2939