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Promoting sustainable travel modes for commute tours: A comparison of the effects of home and work locations and employer-provided incentives

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ABSTRACT

By using data from the 2011 Oregon Household Activity Survey, conducted in the Portland, OR, metropolitan area, the authors conduct tour-based analyses of commute mode choice and apply them to evaluate and compare the effects of three sets of variables: the built environment at home, the built environment at workplace, and employer-provided financial incentives. The analysis results suggested that compared to the built environment at home, the built environment at workplace showed more additional explanatory power, illustrating the importance of including work-location-related variables in the models that simulate commute mode choice and trip chaining. Furthermore, we found that employer-provided financial incentives, in particular, parking fees at workplaces and the provision of subsidized transit passes, could also be very efficient policy levers to encourage commuters to use more sustainable commute modes, especially public transit. While the model results clearly show that the effects of many variables vary by tour complexity, we did not find strong evidence to the hypothesis that trip chaining creates a barrier to shifting commuters' travel mode from auto to nonauto modes.

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1. Introduction

Although commute trips account for less than one-third of vehicle miles traveled by American households (Federal Highway Administration, 2011, p.15), they are major targets of many travel management policies, as they mainly occur during peak hours and are associated with severe traffic congestion (Maat & Timmermans, 2009; Strathman, Dueker, & Davis, 1994; Su & Zhou, 2012). This congestion associated with private cars, which make up the dominant share of commute mode choice, results in negative economic and environmental externalities such as loss of time, air pollution, and wasted energy resources (Shiftan & Barlach, 2002). Many studies have evaluated strategies that can be used to encourage commuters to shift from car travel to more sustainable modes, such as transit, biking, and walking. However, most of them have relied on trip-based models and have considered only one type of strategy. By using data from the 2011 Oregon Household Activity Survey, conducted in the Portland, OR, metropolitan area, this study conducts tour-based analyses of commute mode choice and applies them to evaluate and compare the effects of three sets of variables: the built environment at home, the built environment at workplace, and employer-provided financial incentives.

This article intends to contribute to the literature by addressing three hypotheses that have not been fully tested in previous studies. First, despite the vast number of empirical studies on the relationship between the built environment and commute mode choice, most of them have focused on the built environment at home locations. In this study, we develop a comprehensive set of variables that measure the built environment at both home and work locations and compare their relative impacts on commute mode choice in a systematic way. The advantage of including work-location-related variables in the model is that compared to home-location-related variables, they are less likely to be subject to the self-selection problem as people have much less flexibility in choosing where they work than where they live (Chatman, 2003). Our hypothesis is that work locations have an important impact, if not a more important impact than home locations on commute mode choice and tour pattern.

Second, most previous studies of the effect of the built environment on commute mode choice are trip based, treating travel as if it were for a single purpose with a single destination. In this study, we conduct tour-based analyses that use tours rather than individual trips as the basic unit of analysis. Tour-based analyses allow us to consider commuters' mode choice and tour complexity simultaneously. This has considerable behavioral appeal if, as has been found in other studies, people decide on their travel modes for the entire tour before leaving home (Frank, Bradley, Kavage, Chapman, & Lawton, 2008). The assumption behind the joining of commuters' mode choice decision with their decision on the tour pattern in the model is that the impacts of home and work locations on the utility of a commute mode vary with the level of tour complexity.

In addition, there has been speculation that the importance of the built environment—especially that of the workplace—

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might be at least partially due to parking fees and the financial subsidies provided by employers (Chatman, 2003). However, few studies have been able to test this hypothesis. In this study, we develop two variables that represent priced parking at workplace and employer-subsidized transit passes. The purpose for the inclusion of these two variables in the model is to test the hypotheses that employer-provided incentives are an effective policy tool to encourage the use of more sustainable commute modes and that their presence in the model tends to attenuate the effects of work-location-related variables.

The remainder of the article is organized as follows. Section 2 reviews the relevant literature. Section 3 describes the data and the method that we have used to conduct tour-based analyses. Section 4 discusses the model results. Section 5 concludes by discussing the policy implications of the major findings and the limitations of the study.

2. Literature review

Existing studies on the impact of the built environment on commute mode choice have mostly focused on residential locations. Recent studies, however, have consistently shown that the built environment at the workplace has a significant effect, and in some cases even greater effects than the built environment at home, on commute mode choice. "Measuring urban form at both trip ends provides a greater ability to predict travel choices than looking at trips ends separately" (Frank & Pivo, 1994, p. 44).

The measurement of the built environment at the workplace has varied among studies. A commonly used measure is employment density. Several studies have shown that employment density at workplace is positively associated with the use of non-auto modes in commute trips (Barnes, 2005; Chatman, 2003; Chen, Gong, & Paaswell, 2008; Frank & Pivo, 1994; Lee, Gorden, Moore, & Richardson, 2011; Shiftan & Barlach, 2002), though such a positive relationship might not be linear (Frank & Pivo, 1994) and the magnitude of the effect varies by city and country (Zhang, 2004; Zhao, 2013). Some studies have also shown that employment density at workplace exerts more of an influence on commute mode choice than residential density at home even after many confounding factors are controlled for (Chen et al., 2008; Zhang, 2004).

In addition to employment density, previous studies have also tested several other workplace attributes. For example, Frank and Pivo (1994) found that in addition to density, mixed land use at the workplace also increased transit usage and walking. The study by Chatman (2003), however, did not find a significant effect of the presence of retail use at the workplace on commute mode choice. Lee et al. (2011) identified 14 workplace neighborhood types by cluster analysis of broad indicators such as density, street design, and transit and highway accesses in the four largest Californian metropolitan areas. They found that workplace type mattered more than residence in explaining variations in public transit commuting. Maat and Timmermans (2009) found that the residential environment affected car use in commute trips only for single earners, but characteristics of work locations affected all commuters, especially dual earners.

Most existing studies on the relationship between the built environment and commute mode choice are trip based. However, research has indicated that, as a response to changing social, cultural, and economic conditions in the United States, trip-making behavior has become more complex both spatially and by purpose (Hensher & Reyes, 2000; Levinson & Kumar, 1995; McGuckin, Zmud, & Nakamoto, 2005; Strathman et al., 1994). For example, Van Acker and Witlox (2011) found that the relationship between land use and commuting differed between work-only tours and more complex commute tours. Chen et al. (2008) found car use tended to increase for complex commute tours. In their study in the Seattle, WA, region, Frank et al. (2008) also confirmed that the tour-based approach increased the ability to understand the relative contribution of urban form, time, and costs in explaining mode choice and tour complexity for both work-related and non-work-related travels. Their model results showed that travel time was the strongest predictor of mode choice, whereas urban form was the strongest predictor of tour complexity.

The impacts of parking fees and financial subsidies provided by employers have been less studied than the effects of the built environment on commute mode choice. Chatman (2003) suspected that the importance of the built environment—especially that of the workplace —might be at least partially due to parking fees and the financial subsidies provided by employers. A study by Peng, Dueker, and Strathman (1996) examined the effect of parking charges on commute mode choice in Portland, OR, and showed that a parking fee was an effective tool to encourage commuters to shift from driving alone to alternative modes and that the effectiveness varied by residential and employment locations. Another study, also conducted in Portland, OR, by Hess (2001) confirmed that an increase in the cost of parking at work sites could significantly reduce the percentage of people who drove alone to work. Recent research by Su and Zhou (2012) also indicated that commuters in Seattle, WA, were less likely to drive alone to work when employers charged higher fees for parking for single-occupant vehicles, provided reserved parking for high-occupancy vehicles, and offered financial subsidies to those who commuted by alternative modes.

3. Method and data

3.1 *Study area*

This study focuses on the Portland, OR, metropolitan area, which is widely viewed as a national leader in transit-oriented development and smart growth in the United States. In the past three decades, the Portland metropolitan area has designed and implemented many policies to promote compact urban form and sustainable transportation. Several non-auto-travel modes such as bus, light rail, commuter rail, biking, and walking are readily available not only in Portland's central city but also in its suburban areas. In addition to its efforts to promote sustainable travel through the implementation of changes in urban form and transportation infrastructure, the Portland region also implemented the Employee Commute Options program, which has been identified as a travel demand management program with a structure that is considered a best practice in the

United States (Su & Zhou, 2012). Under this program, employers with more than 100 employees must develop a travel reduction plan and are expected to provide financial incentives to employees who commute by alternative modes, such as transit pass subsidies (Metropolitan Council, 2010). As such, the Portland metropolitan area provides an interesting environment for comparison of the effectiveness of different strategies in encouraging a shift of the commute mode from car travel to alternative modes.

3.2 *Data*

The household travel data used in this study were from the 2011 Oregon Household Activity Survey, which provides trip, place, person, vehicle, and household sociodemographic data. Participants in the survey reported their activity and travel information during a specific 24-h period. This analysis focuses on responses from the Portland region only, which includes three counties: Clackamas, Multnomah, and Washington. When the travel survey was designed, an oversampling strategy by geography was adopted to capture the diversity of the population and travel patterns. The survey oversampled geographies with high concentration of transit-using households, households that were more likely to walk to bus and light rail transit, and households that used more nonmotorized modes of transportation. Some intercept samples were also collected at the park-and-ride lots to capture commuters who drove to transit for work tours.

Geographical information system (GIS) data on land use and transportation infrastructure in the study area is from Metro's Regional Land Information System (RLIS). RLIS provides parcel-level land use data and very detailed spatial and physical attributes of local streets, sidewalks, and bike paths and lanes. These highly detailed and spatially disaggregated data permit us to measure the built environment at both home and work locations in a very accurate way without a reliance on predetermined polygonal units. We also obtained morning 2-h travel skims containing drive and transit travel times between pairs of traffic analysis zones (TAZs) from Metro. The travel skims data were used to calculate regional accessibility by car and transit at both home and work locations.

3.3 *Tour-based analysis*

This study conducts tour-based analyses that use tours rather than individual trips as the basic units of analysis. Each tour represents a sequence of trips that start and end at home. Our analyses focus on commute tours, which include work trips and possibly nonwork trips. In the model, it is assumed that commuters decide their travel mode and tour pattern simultaneously.

Tour pattern was measured on the basis of the number of activities involved in a tour. A simple commute tour involves only one activity: work. A complex commute tour involves other activities besides work, such as shopping and eating outside of work. These activities could occur before, after, or at work. Mode change, such as parking the car to catch a light rail train on the journey to work, was not considered an activity. Our data set shows that in the Portland metropolitan area, about 48.3% of commute tours were simple tours, which represent the traditional assumption on the profile of a commute trip: home–work–home. More than half (51.7 percent) of commute tours involved at least one nonwork activity, illustrating the appropriateness and importance of modeling commute mode choice with tour-based models rather than trip-based models. For simplicity, this analysis categorized commute tours into two basic groups on the basis of their tour pattern: simple and complex.

Similar to Frank et al. (2008), if a tour involves more than one travel mode, the mode of the tour is determined by a priority order of modes: (1) drive to transit (mainly park and ride and kiss and ride), (2) walk to transit, (3) car, (4) bike, and (5) walk. It is assumed that the auto mode is available for all commuters (as drivers or passengers). Drive to transit was also assumed to be available for all commuters. Walk to transit was available if the total transit travel time was less than or equal to 2 h, the number of transfers was less than four, the time needed to walk to the transit station was less than or equal to 30 min, and each waiting time was less than or equal to 15 min. Biking was available for tours that were less than or equal to 12 miles and walk was available only for tours that were less than or equal to 3 miles.

Combining commute mode and tour pattern resulted in a total of 10 possible alternatives (2×5). Since in this study we were more interested in investigating strategies that encourage commuters to shift from auto to alternative modes, "drive, simple tour" was used as the reference to which the other alternatives were compared. Furthermore, because of the small number of complex walk tours, they were combined with simple walk tours into one "walk tour" category. As such, in our models, each commuter faced a total of nine possible alternatives in their choice set. Table 1 shows the shares of alternatives and modes and the complexity of each mode measured as the average number of activities in a tour by that mode. In addition to the average number of activities in a tour, the average number of stops in a tour by each mode is also presented in Table 1. Note that mode change and transfer were not considered activities in this analysis.

3.4 *Explanatory variables*

Table 2 presents the explanatory variables that were used to predict commute mode and tour pattern in our models. As Table 2 indicates, explanatory variables were categorized into four groups: the built environment at home, the built environment at workplace, employer-provided financial incentives, and control variables. Each of the first three groups represents a set of variables that planning policies can target to intervene to promote more sustainable commute modes.

The built environments at home and work locations were measured by sliding neighborhoods, which are circular areas of a half-mile radius centered on homes and workplaces. The half-mile buffer distance is based on the distance that can be covered by walking in about 10 min (Knoblauch,

Table 1. Alternative share and tour complexity.

Alternative	Frequency	Percent (%)	Percent by mode (%)	Average of number of activities in a tour by mode*	Average of number of stops in a tour by mode
Car, simple	1319	34.7	76.7	2.32	2.36
Car, complex	1598	42.0			
Drive to transit, simple	166	4.4	9.0	2.13	6.87
Drive to transit, complex	176	4.6			
Walk to transit, simple	168	4.4	6.9	1.71	7.04
Walk to transit, complex	94	2.5			
Bike, simple	119	3.1	5.2	1.90	1.90
Bike, complex	79	2.1			
Walk	86	2.3	2.3	1.41	1.41
Total	3805	100	100	2.22	3.04

*Mode change was not considered an activity.

Pietrucha, & Nitzburg, 1996). As indicated in Table 2, for each home location, we had three variables related to land use patterns: residential density, job–home balance, and mixed land use. Total employment was used to represent job opportunities within walking distance of a residential location. Four variables were developed to measure street design and neighborhood walkability: street density, sidewalk completeness, street intersection ratio, and street intersection density. The ease of riding a bicycle (bikeability) was measured by a home's distance to the nearest high-quality bike route and the density of high-quality bike routes within a half mile. High-quality bike routes refer to bike boulevards and local and regional multiuse paths in the Portland metropolitan area (Broach, Dill, & Gliebe, 2012). The variables for

Table 2. Explanatory variable.

Variable	Explanation
Built environment at home	
Residential density	Housing unit/land occupied within a half mile.
Job-home balance	The ratio between employment and housing units within a half mile.
Mixed land use	The ratio between service employment and housing units within a half mile.
Employment opportunity	Amount of employment within a half mile.
Walkability:	
Street density	Length of streets within a half mile.
Sidewalk completeness	Percentage of streets with sidewalk within a half mile .
Intersection ratio	Number of street intersections with 3+ valences/(number of street intersections + number of Cul-deSacs) within a half mile.
Intersection density	Number of 3-or-more-way street intersections with 3-way valences within a half mile.
Accessibility to high-quality bike routes:	
Distance to bike route	Distance to the nearest high-quality bike route (mile).
Bike route density	Length of high-quality bike routes within a half mile.
Transit accessibility	Accessibility for employment purpose by transit at home locations.
Distance from home to CBD	Straight-line distance from home to CBD.
Built environment at workplace	
Employment density	Amount of employment within a half mile.
Retail accessibility	Amount of retail employment within a half mile.
Walkability:	
Street density	Length of streets within a half mile.
Sidewalk completeness	Percentage of streets with sidewalk within a half mile.
Intersection ratio	Number of street intersections with 3+ valences/(number of street intersections + number of Cul-deSacs) within a half mile.
Intersection density	Number of street intersections with 3+ valences within a half mile.
Accessibility to high-quality bike routes:	
Distance to bike route	Distance to the nearest bike boulevards and local or regional multi-use paths (mile).
Bike route density	Length of bike boulevards and local and regional multi-use paths within a half mile.
Transit accessibility	Accessibility for employment purpose by transit at home locations.
Work in CBD	Straight-line distance from home to work.
Employer-provided financial incentives	
Parking charge	Employer does not provide free parking (yes = 1; no = 0).
Transit pass	Employer provides transit pass for free or at a reduced cost (yes = 1; no = 0).
Control variables	
Household income	Households are categorized into four groups: low income (<$50,000), medium income ($50,000-$99,999), high income ($100,000+), and those did not report their income in the survey.
Household size	Number of household members within household.
Presence of kid(s)	Presence of kid(s) in the household.
College education	Person has a bachelor or higher degrees (yes = 1; no = 0).
Home-work distance	Straight-line distance from home to work.

the built environmental at workplace were calculated in similar ways. The difference is that employment density and retail accessibility were used to measure density and mixed use at workplace.

Regional accessibility by transit was included in the model to represent the availability of employment (residential) opportunities and transit at home (work) locations. Transit accessibility for employment purposes for a home that is located in TAZ_i was calculated by the use of the following formula (Meyer & Miller, 2001, p. 336):

$$Accessibility^i_{home} = \sum_{j=1}^{J} \exp(-\beta * time_{ij}) * employment_j$$

in which $Accessibility^i_{home}$ measures the transit accessibility to employment in all other TAZs in the region for TAZ_i, β is a parameter indicating the sensitivity of trip making to travel time,[1] $time_{ij}$ is the travel time by transit from TAZ i to TAZ j, and $employment_j$ is the number of jobs in TAZ j.

The transit accessibility of a workplace located in TAZ_i was calculated as

$$Accessibility^i_{work} = \sum_{j=1}^{J} \exp(-\beta * time_{ij}) * household_j$$

in which $Accessibility^i_{work}$ measures the transit accessibility to all other TAZs in the region for TAZ_i, β is a parameter indicating the sensitivity of trip making to travel time, $time_{ij}$ is the travel time by transit from TAZ i to TAZ j, and $household_j$ is the number of households in TAZ j.

In addition to the built environment and transit accessibility at home and work locations, we also developed two variables to control for the effects of the central business district (CBD) in Portland. At home locations, we measured their straight-line distances to the CBD. For work locations, we created a variable indicating if a commuter worked in the CBD.

As mentioned earlier, the Employee Commute Options program implemented for the Portland region requires employers with more than 100 employees to develop travel reduction plans and expects them to provide financial incentives to their employees to reduce single-occupant vehicle traffic (Metropolitan Council, 2010). In this analysis, we used two variables to examine the effects of this program. The first indicates whether a parking fee was charged at a workplace, and the second indicates if an employer provided transit passes for free or at a reduced cost to its employees.

Lastly, we controlled for a set of household and personal sociodemographic variables in our models, such as household income, household size, the presence of kid(s) in the household, and the commuter's education level. The model also controlled for the straight-line distance from home to work.

3.5 *Factor analysis*

It is well recognized that neighborhood environment variables tend to be correlated with each other (Miles & Song, 2009; Shay & Khattak, 2012). Our data analyses confirmed that there are strong statistically significant correlations between some built environmental variables at both home and work locations. The inclusion of all these highly correlated variables in the model may result in cofounding effects and muticollinearity problems (Shay & Khattak, 2012). To reduce data redundancy and potential problems caused by high correlations between these variables, we performed factor analyses on the built environment variables at home and work locations, respectively. The results of the factor analyses are shown in Table 3.

As indicated in Table 3, two factors were extracted from the 10 variables for home locations, and two factors were extracted from the eight variables for work locations. The factor analysis results show that the two home location factors accounted for about 63.7% of the total variation in the 10 home location variables, and the two work location factors represented about 75.5% of the total variation in the eight work location variables. In Table 3, variables are listed in the order of their loading, which represents both the correlation between the variables and the factor and the weighting of the variables for each factor.

The first home location factor is related to neighborhood walkability and bikeability. The signs of the factor loading indicate that a higher score on home location factor 1 is

Table 3. Rotated factor loadings of home/work.

Location variables	Extracted factors	
Extracted factor	Factor 1	Factor 2
Rotated factor loadings of home location variables		
% of variance	39.75%	23.93%
Loading variables:		
Intersection density	.928	
Street density	.906	
Sidewalk completeness	.779	
Intersection ratio	.766	
Bike route density	.674	
Distance to bike route	−.620	
Employment opportunity		.845
Job-home balance		.756
Residential density		.727
Mixed land use		.665
Rotated factor loadings of work location variables		
% of variance	55.09%	20.41%
Loading variables:		
Retail accessibility	.923	
Employment density	.917	
Intersection density	.904	
Street density	.843	
Intersection ratio	.764	
Sidewalk completeness	.593	
Distance to bike route		−.926
Bike route density		.515

Notes. Only loadings for all factors $\geq |0.5|$ are presented.
The extraction method is principal component analysis; the rotation method is Varimax with Kaiser normalization.

[1] β was calculated as the negative reciprocal of the average commute time in Portland, which was about 24.3 min according to the 2007–2011 American Community Survey.

associated with better walkability and a higher level of accessibility to high-quality bike routes. The second home location factor mainly reflects the land use pattern at home. A higher score on home location factor 2 represents higher density and more opportunities for work and nonwork activities.

The first work location factor basically reflects a high correlation between employment density and walkability at workplaces. A high score on work location factor 1 is associated with higher levels of employment density and walkability. Work location factor 2 indicates the accessibility to high-quality bike routes and a higher score indicates better access to high-quality bike routes.

3.6 *Model estimation*

We first estimated a series of nested logit (NL) models since previous studies (Hensher & Reyes, 2000; Peng, Dueker, & Strathman, 1996) indicated that the alternatives in the subset might share unobserved attributes. NL model tree structures that have been tested included nesting of the nine alternatives by tour complexity (simple/complex), general travel mode (car /public transit /nonmotorized), specific travel mode (car /drive to transit /walk to transit /bike /walk), and so forth. We finally settled with the nested structure based on tour complexity, with tours by nonmotorized modes being separated as one subnest. Because of space limitation, we do not present the formulas for the multinominal logit (MNL) and NL models, which are available from many textbooks on discrete choice analysis (e.g. Train, 2003; Hensher, Rose, & Greene, 2005). Note that we used a weighting variable in all models to correct for the expected sample bias caused by the oversampling and intercept-sampling strategies.

4. Model results

In Table 4, we present the results of three models. The three models share the same control variables. In model 1, we include the variables that measure the built environment at home. In model 2, the built environment at workplace is added. In model 3, we add the two variables that represent employer-provided financial incentives. The specification of the three models in Table 4 were achieved by a systematic process of eliminating variables found to be statistically insignificant in previous specifications with considerations of model parsimony. As indicated in Table 4, models 2 and 3 yielded one statistically significant nest parameter for alternatives for motorized complex tours, indicating that unobserved similarities existed between them. In model 1, because none of the nest structures that we have tested yielded significant nest parameters, the NL model collapsed to a simple MNL model form.

4.1 *General comparison between models*

As presented in Table 4, the overall goodness-of-fit of model 1 in terms of adjusted rho-squared value was 0.259, which is slightly higher than that of the model with control variables only[2] (0.259 vs. 0.245). In model 2, with the inclusion of the variables that represent the location of and the built environment at workplace, the adjusted rho-squared value was improved from 0.259 to 0.318. After controlling for the built environment at both home and workplace, the inclusion of the two variables representing employer-provided financial incentives improves the adjusted rho-squared value slightly, from 0.318 to 0.332. Our analyses also show that when the built environment at home and workplace are not controlled for in the model,[3] the inclusion of these two variables improves the model goodness of fit significantly, from 0.259 (model with control variables only) to 0.300 (model with control variables plus the two employer-provided incentives). It appears that after controlling for the socioeconomic variables, the built environment at workplace and employer-provided financial incentives showed more additional explanatory power than the home location related variables in explaining commuters' travel mode choice and tour complexity.

All the three models in Table 4 include the variables that represent the location and the built environment at home. In general, the effects of these variables are consistent across the three models. The only exception is the variable that measures the distance from home to CBD. Its influence on transit use turns statistically insignificant after controlling for the built environment at workplace, which is likely to be a result of their negative correlation. The inclusion of the two variables representing employer-provided incentives tends to weaken the significance of the effects of working in CBD on public transit. This is expected because employers in downtown Portland are more likely to offer subsidized transit pass but less likely to provide free parking. The inclusion of these two variables in the model, however, does not significantly change the estimated effects of the built environment at workplace.

4.2 *Effects of individual variables*

Next, we discuss the specific effects of individual variables, focusing on the variables that are related to the three strategies. The discussion is based on the results of model 3, which is the most comprehensive one among the model specifications that we have tested. As mentioned earlier, among the nine alternatives, "drive, simple tour" was used as the reference to which the other alternatives were compared.

4.2.1 *Home location variables*

In the model, two factors extracted from the 10 home location variables were used to measure the effects of the built environment at home on commute mode choice and tour complexity. As mentioned earlier, a higher score on home location Factor 1 mainly reflects better neighborhood walkability and bikeability. The model results show that this factor had a positive effect on complex bike tours, but its effect on simple bike tours was not statistically significant. This result probably reflects the fact that the bikeability variables mainly capture the biking environment

[2] The model results are not presented but are available upon request.
[3] Results are not presented but are available upon request.

Table 4. Model results.

	Model 1		Model 2		Model 3	
Logsum parameter	N.A					
Complex motorized tours			0.682	-2.98	0.651	-3.52
Simple motorized tours			1.000	fixed	1.000	fixed
Nonmotorized tours			1.000	fixed	1.000	fixed
Home location variables						
Home location Factor 1						
Drive to transit, simple	-0.523	-3.86	-0.473	-3.65	-0.637	-5.03
Walk to transit, simple	0.334	3.03	0.347	4.06	0.480	4.87
Bike, complex	0.762	3.96	0.677	3.49	0.691	3.59
Home location Factor 2						
Drive to transit, simple	-0.550	-3.59	-0.530	-3.28	-0.560	-3.36
Walk to transit, simple	–	0.103	1.98	0.134	2.52	
Car, complex	-0.131	-3.14	-0.107	-2.82	-0.113	-3.02
Accessibility by transit at home						
Drive to transit, simple	0.216	2.77	0.274	3.39	0.242	3.04
Walk to transit, simple	-0.234	-2.23	–		-0.207	-2.02
Walk to transit, complex	0.805	4.79	0.605	4.15	0.575	4.12
Car, complex	–	0.063	2.61		0.052	2.18
Distance from home to CBD						
Drive to transit, simple	-0.075	-3.16	–		–	
Drive to transit, complex	-0.066	-3.54	–		–	
Walk to transit, simple	-0.059	-2.41	–		–	
Bike, simple	-0.205	-5.86	-0.179	-4.18	-0.185	-4.28
Bike, complex	-0.208	-3.03	-0.150	-2.17	-0.170	-2.51
Walk	–		-0.107	-4.48	–	
Work location variables						
Work location Factor 1						
Drive to transit, simple			0.516	4.19	0.749	7.78
Drive to transit, complex			0.559	5.54	0.687	7.49
Car, complex			0.249	5.14	0.307	4.92
Bike, simple			0.891	5.29	0.977	5.67
Bike, complex			0.759	5.25	0.701	5.42
Walk			1.063	6.01	0.580	2.96
Work location Factor 2						
Drive to transit, simple			–		0.471	3.14
Walk to transit, simple			-0.617	-5.54	-0.591	-5.14
Walk to transit, complex			-0.552	-3.96	-0.541	-4.22
Car, complex			0.161	4.21	0.132	3.29
Bike, simple			0.664	3.49	0.584	3.09
Bike, complex			0.478	1.96	–	
Accessibility by transit at work						
Drive to transit, simple			0.927	3.85	–	
Drive to transit, complex			0.575	3.22	–	
Walk to transit, simple			2.071	9.16	2.042	9.28
Walk to transit, complex			1.346	5.03	1.241	4.97
Work in CBD						
Drive to transit, simple			1.412	5.08	–	
Drive to transit, complex			1.093	4.73	–	
Walk to transit, simple			0.966	5.07	–	
Walk to transit, complex			0.868	4.44	–	
Car, complex			–		-0.417	-3.56
Bike, simple			-1.245	-3.67	-1.371	-4.06
Employer-provided financial incentives						
Parking charge						
Drive to transit, simple					2.481	10.55
Drive to transit, complex					1.653	7.83
Walk to transit, simple					1.113	6.23
Walk to transit, complex					1.320	7.23
Car, complex					0.439	3.63
Walk					2.410	7.17
Transit pass						
Drive to transit, simple					1.261	6.07
Drive to transit, complex					0.391	2.52
Walk to transit, simple					1.089	5.67
Walk to transit, complex					0.832	3.94
Control variables						
Low household income						
Drive to transit, simple	-0.659	-3.31	0.650	3.42	0.828	4.13
Walk to transit, simple	0.573	3.63	0.835	4.94	0.921	5.32
Walk to transit, complex	1.003	4.69	0.851	3.76	0.826	3.83
Bike, complex	0.627	2.28	0.807	2.88	0.772	2.75
High household income						

(*Continued on next page*)

Table 4. Model results (*Continued*).

	Model 1		Model 2		Model 3	
Drive to transit, simple	-0.900	-3.78	-0.958	-3.79	-1.045	-4.03
Drive to transit, complex	-0.405	-2.07	–		-0.640	-2.75
Walk to transit, simple	-0.587	-2.60	-0.572	-2.50	–	
Car, complex	0.274	3.31	0.315	4.28	0.325	4.43
Household income not reported						
Drive to transit, complex	-1.045	-3.07	–		–	
Bike, simple	0.597	2.00	0.617	2.05	0.629	2.09
Bike, complex	1.117	3.24	1.203	3.46	1.213	3.49
Presence of kid(s)						
Drive to transit, simple	0.630	2.52	–		–	
Car, complex	0.761	7.60	0.615	6.24	0.657	6.79
Household size						
Drive to transit, simple	-0.313	-3.28	–		–	
Drive to transit, complex	-0.137	-2.12	–		–	
Car, complex	-0.185	-4.85	-0.138	-3.85	-0.150	-4.21
Bike, complex	0.343	3.55	0.358	3.63	0.351	3.56
College education						
Walk to transit, simple	-0.451	-2.89	-0.688	-4.22	-0.754	-4.61
Walk to transit, complex	0.621	2.78	0.397	2.35	–	
Car, complex	0.426	5.63	0.408	5.68	0.375	5.30
Bike, simple	–		0.538	2.26	–	
Bike, complex	1.003	3.12	0.998	3.07	0.927	2.86
Walk	0.624	2.50	–		–	
Home-work distance						
Drive to transit, simple	0.092	5.67	0.055	2.66	–	
Drive to transit, complex	0.060	3.58	–		–	
Walk	-0.878	-2.97	-1.003	-3.40	-1.012	-3.46
Log likelihood at zero	-6978		-6978		-6978	
Log likelihood at convergence	-5125		-4697		-4594	
Adjusted rho squared wrt zero	0.259		0.318		0.332	
Number of Cases	3805		3805		3805	

Notes. For each model, the first column reports coefficients and the second column reports t-values. "–" indicates that the variable was dropped because it was not statistically significant at 5% level.
In model 1, because none of the nest structures that we have tested yielded significant nest parameters, the NL model collapsed to a simple MNL model form.
To save space, the estimation results of alternative specific constants are not presented in the table.

in a commuter's home neighborhood but not necessarily along the rest of the route to work. It might also be an indication that complex commute trips by bike that include trips for non-commute purposes are more sensitive to bike route quality than simple commute tours by bike, which confirms the findings of Broach, Dill, and Gliebe (2012) that Portland cyclists are less sensitive to the travel environment on commute trips than on noncommute trips. The results also showed that commuters in residential neighborhoods with greater walkability and bikeability were more likely to walk to transit but less likely to drive to transit for simple commute tours, which also makes sense.

A higher score on home location Factor 2 indicates a higher density and more work and nonwork opportunities surrounding the residential location. The estimation results suggested that commuters in neighborhoods with a higher density and a higher level of mixed use were less likely to drive to transit for simple tours and drive for complex commute tours, but more likely to walk to transit for simple tours. These results might reflect the lack of park-and-ride lots in dense areas and their increased attractiveness of walking to transit over other travel modes.

A higher level of transit accessibility at home was associated with a greater chance of driving to transit for simple tours and a greater chance of walking to transit for complex tours. But it showed a negative effect on the probability of walking to transit for simple tours, which is hard to explain.

After controlling for the built environment at workplace, the distance from home to work did not show a strong effect on the probability of using public transit for simple and complex tours. The only significant effect was that commuters who lived farther away from their workplaces were less likely to ride bicycles for both simple and complex tours.

In general, our model results indicate that the effects of the two home location factors mainly focused on simple transit modes: Commuters who live in locations with better walkability and bikeability, higher density, and higher levels of mixed use were more likely to undertake simple tours by walking to transit. But the effects of the two factors on the chance of walking to transit for complex tours are not statistically significant.

4.2.2 *Work location variables*

The estimation results for work location Factor 1, which represents employment density and walkability at workplace, show that commuters working in places with higher employment densities and higher levels of walkability were more likely to drive to transit, ride bicycles, and walk for work, regardless of tour complexity. Work location Factor 2, which mainly indicates accessibility to high-quality bike routes from a workplace, showed a positive and significant effect on complex tours by biking, which is consistent with expectations. Its effect on simple bike tours, however, was not statistically significant. In addition, better accessibility to high-quality bike routes at workplace showed positive effects on driving to transit for simple tours and driving a car for complex tours, but significant and negative effects on walking to transit for both simple and complex tours, a finding which is difficult to explain.

As expected, transit accessibility at workplace had a positive and significant effect on walking to transit for work, but the effect was not statistically significant for driving to transit for work, regardless of tour complexity.

We also have a variable indicating whether a commuter works in downtown Portland to capture work-location-related effects that are not captured by the variables mentioned previously. The models results show that after controlling for neighborhood characteristics at workplace discussed previously, the influence of this variable was only significant for complex auto tours and simple bike tours: Commuters who worked in downtown Portland were less likely to undertake complex tours by car and simple tours by bike.

Overall, the two work location factors seemed to have greater effects than the two home location factors on commuters' mode choice and tour pattern. It also indicates that better walkability and bikeability at workplace are more effective in encouraging commuters to ride bikes and walk than those at home.

4.2.3 *Employer-provided financial incentives*

The model results show that the two variables for employer-provided financial incentives showed significant and positive effects in encouraging commuters to use transit. Commuters who had to pay for parking at workplace and those who received subsidized transit passes from their employers were more likely to use transit (by walking and driving) for both simple and complex tours. In addition, commuters who had to pay for parking at their work locations were also more likely to walk to work and to undertake complex tours when they drove.

However, it is important to note that because of data limitation, we were not able to control for the potential self-selection issue caused by the two variables, which could be endogenous when there is a certain amount of self-selection in learning about the availability of the two incentives. We believe that people working in a particular workplace are likely to know about whether there is free parking available, but they may not know whether subsidized transit passes are available. Commuters who already used transit may be more likely to know the availability of transit subsidy provided by employers. Given that subsidized transit passes are more likely to be offered in areas that are well served by transit such as downtown Portland, we test how the indicator of working in CBD affects the estimation results of subsidized transit pass. It shows that the estimation results for subsidized transit pass are quite robust and consistent across models with and without controlling for working in CBD, indicating that self-selection might not be a serious issue in the model.

4.2.4 *Control variables*

As is often the case, sociodemographic variables played a significant role in determining commute mode and tour pattern. Compared with commuters in medium-income households, commuters in low-income households were more likely to walk to transit for both simple and complex tours, drive to transit for simple tours, and ride bicycles for complex tours. Commuters in high-income households were less likely to drive to take transit and more likely to form complex tours when they chose to drive. The presence of kid(s) in a household seemed to increase the chance of undertaking complex tours by car. After controlling for the presence of kid(s), a larger household size reduced the probability of undertaking complex tours by car but increased the chance of undertaking complex tours by bike. Commuters with a college degree or higher were less likely to undertake simple tours by walking to transit, but they were more likely to use biking for complex tours and form complex tours when they decided to drive for work. Lastly, as the distance from home to work increased, commuters were less likely to walk for work.

5. Conclusion and discussion

Using the recent Oregon Household Activity Survey data in the Portland metropolitan area, this study developed a series of MNL and NL models to evaluate and compare the variables that were expected to encourage commuters to shift from car to alternative modes with consideration of tour complexity. We compared the effects of two groups of variables that measured the built environment and transit accessibility at both home and work locations. The model results suggested that the built environment at the workplace showed more additional explanatory power than the variables for home locations, illustrating the importance of including work-location-related variables in the models that simulate commute mode choice and trip chaining.

The other advantage of including variables for the built environment at workplace in the model is that they are less likely to be subject to the self-selection problem as people have much less flexibility in choosing where they work than where they live (Chatman, 2003). One important policy implication of this finding is that planning policies might be more effective in encouraging commuters to take alternative travel modes other than driving cars for work if they focused more on workplaces than on residential areas (Barnes, 2005). Also, new urbanist policies are less likely to encounter resistance in workplaces, such as the central city and suburban employment subcenters (Barnes, 2005; Chatman, 2003).

Furthermore, we found that employer-provided financial incentives, in particular, parking fees at workplaces and the provision of subsidized transit passes, could also be very efficient policy levers to encourage commuters to use more sustainable commute modes, especially public transit. The inclusion of these two incentives in the model attenuates the effect of the variable that indicates if a commuter works in the CBD, but it does not significantly change the estimated effects of the built environment at workplace. In addition, financial incentive programs tend to be less costly and more efficient than planning policies that aim to change the built environment, because it is easier for such programs to target certain groups of travelers.

In addition, the model results clearly show that the effects of these variables vary by tour complexity. Many of them have significant effects on simple tours in a mode but insignificant effects on the same mode of complex tours, and vice versa. But the model results did not provide strong evidence to the hypothesis that trip chaining creates a barrier to shifting commuters' travel mode from auto to nonauto modes.

One limitation of this study is that, because of data limitations, we were not able to take into account the attitudes and preferences of commuters. A number of studies have shown that household decisions on residential location choice and travel mode choice are closely related (Chen et al., 2008; Kriek, 2003). Commuters who are more aware of environmental issues may choose to live in more compact neighborhoods, own fewer vehicles, and use nonauto modes to travel for work. We leave this issue for future research.

In addition, to minimize data redundancy and potential multicollinearity problems, we performed factor analyses on location-related variables and used the extracted factors in our model estimations. Compared to studies that have used individual variables, this operation allows us to test models with less bias, but it makes it harder to tell exactly which individual variable(s) were at work.

Lastly, this is a cross-sectional study and does not provide as strong evidence of the effects of various strategies as a longitudinal study would. This study has focused on work travel only. It will be interesting to evaluate the effects of the built environment at home locations and primary destinations of nonwork tours and compare them with the results of this study.

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