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The Effects of Free Parking on Commuter Mode Choice: Evidence from Travel Diary Data

By: Daniel Baldwin Hess

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The Ralph & Goldy Lewis Center for Regional Policy Studies
UCLA, School of Public Policy and Social Research
3250 Public Policy Building
Los Angeles CA 90095-1656
Director: Paul Ong
Phone: (310) 206-4417
Fax: (310) 825-1575
http://www.sppsr.ucla.edu/lewis/
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THE EFFECT OF FREE PARKING ON COMMUTER MODE CHOICE: EVIDENCE FROM TRAVEL DIARY DATA

Daniel Baldwin Hess
Institute of Transportation Studies
University of California, Los Angeles
3250 Public Policy Building, Box 951656
Los Angeles, California, 90095-1656
e-mail dhess@ucla.edu

ABSTRACT

This study assesses the effect of free parking on mode choice and parking demand. A multinomial logit model is developed to evaluate the probabilities that commuters who *do* and who *do not* receive free parking at work will choose to drive alone, ride in a carpool, or use transit for the trip to work in Portland's (Oregon) CBD. The mode choice model predicts that with *free* parking, 62 percent of commuters will drive alone, 16 percent will commute in carpools and 22 percent will ride transit; with a daily parking charge of $6, 46 percent will drive alone, 4 percent will ride in carpools and 50 percent will ride transit. The mode choice model predicts that a daily parking charge of $6 in the Portland CBD would result in 21 fewer cars driven for every 100 commuters. This translates to a daily reduction of 147 VMT per 100 commuters and an annual reduction of 39,000 VMT per 100 commuters. These findings are consistent with previous studies of the effect of parking cost on mode choice. The policy variables that play a part in mode choice decisions for commuters are the parking cost and the travel time by transit, and the results suggest that raising the cost of parking at work sites and decreasing the transit travel time (by improving service and decreasing headways) will reduce the drive alone mode share. The results provide little support for the contention that land use is a significant factor in mode choice decisions.

Key words: parking, mode choice, activity survey, modeling, commuting

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Introduction

When commuters can park their cars free at work, they are more likely to drive alone. American employers provide 85 million free parking spaces for commuters. Approximately 91 percent of commuters in the U.S. drive to work, and 92 percent of the cars driven to work have only one occupant (Shoup 1999).[1] Using data from the 1990 Nationwide Personal Transportation Survey (NPTS), Shoup (1995) estimated that parking is free to the driver for 95 percent of automobile work trips. Employers encourage solo driving to work when they pay part of the cost of the commute trip — the parking cost — while requiring the employee to pay only the driving cost. This leads to a significant reduction in the cost of driving to work, thus encouraging more driving. By offering their employees free parking at work, employers stymie public goals of reducing solo driving and increasing the use of carpooling, transit, walking, and bicycling for the commute to work.

This study assesses the effect of free parking on mode choice and parking demand. I develop a model to estimate the probability that commuters who *do* and who *do not* receive free parking at work will choose to drive alone, ride in a carpool, or use transit for the trip to work. The hypothesis tested is that free parking encourages driving to work — especially in single occupant vehicles. I will also investigate whether drivers who must pay to park at work are more likely to use an alternative mode. I use data from a household activity survey to model the interdependence of parking cost and mode choice. I develop a multinomial logit model of mode choice for the work trip to Portland's (Oregon) central business district (CBD) to evaluate and interpret daily commuting behavior.[2] Unlike other mode choice models, the model developed in this study can predict changes in the factors affecting travel behavior, such as a change in the parking price. The mode choice model predicts that with free parking, 62 percent of commuters will drive alone, 16 percent will commute in carpools and 22 percent will ride transit; with a daily parking charge of $6, 46 percent will drive alone, 4 percent will ride in carpools and 50 percent will ride transit.

Development of a Database for Hypothesis Testing

This study uses data from the *Oregon and Southwestern Washington 1994 Activity and Travel Behavior Survey,*[3] a detailed travel diary that collected data from 4,451 households using a region-wide, two-day activity survey (Cambridge Systematics 1996). The survey, conducted by the Portland

Metropolitan Services District (Portland Metro), recorded what each member in a household did (activity choice), where (location choice), for how long (activity duration), and with whom (activity participation). For each activity that required travel, the survey collected detailed information about the trip.

The survey data consists of 9,471 persons reporting 122,348 activities and 67,981 valid trips. Activities were grouped into 27 categories.[4] Activity/travel data were collected for every household member, regardless of age. Each household was assigned two consecutive travel days to record activities for all household members, and the travel days assigned to households were varied to capture data representing all the days of the week.[5] Households were geocoded to transportation analysis zones (TAZs) in Portland Metro's 1,260-TAZ system. Table 1 summarizes the households, trips, and vehicles for each household that participated in the household activity survey.

Table 1 Household and Transportation Activity Estimates

Measure	**Estimate**
Total households[6]	567,126 households
Average household size	2.3 persons
Average number of vehicles per household	1.73 vehicles
Total trips recorded (all modes)	67,981 trips
Average trip rate per household per day	8.04 trips
Average activity rate per household per day	14.48 activities
Total activities reported	122,348 activities
Travel volume projection	4,599,693 trips

Source: NuStats International, Inc. 1995. *Oregon and Southwest Washington Household Activity and Travel Surveys.*

Geographic Stratification of Survey Respondents

One of the primary goals of the Household Activity Survey was to collect data that could be used to study a variety of transportation-related behavior. The relationship between the built environment and transportation behavior was of particular interest to Portland Metro, the MPO (metropolitan planning organization) for the five-county metropolitan area. The survey was designed to capture enough observations of the less common transportation choices to be able to understand the underlying factors. For these reasons, the sample universe in the Portland Metro area was stratified by geographic "market area" and enriched to include different numbers of transit and park-and-ride users (see table 2). Three geographic strata were used to identify areas suitable for travel by foot and by light rail: (1) urban areas with good pedestrian environments and transit, (2) urban areas with poor pedestrian environments, and (3) areas within the light rail corridor.[7]

Table 2 Geographic Stratification Portland Household Activity Survey

Stratum	Description of Sub-Area
1	Multnomah County
	Urban, good Pedestrian Environment Factor (PEF), land use mix, and transit
2	Urban, bad PEF & transit
3	Urban, good PEF & transit
4	Light rail corridor
5	Remainder of county
6	Clackamas County
7	Washington County
8	Columbia County (partial)
9	Yamhill County (partial)
10	Park-and-Ride Users[8]

Source: NuStats International, Inc. Technical Memorandum, Sample Productivity Plan, updated.

Households in areas defined as having good pedestrian and transit access were oversampled. However, to perform research generalizable to the entire Portland metropolitan area, a weighting system was developed to apply to the sampled households. The geographic weighting system is used in all statistical analyses in this study.

Survey Method

Portland Metro contracted with a survey firm to conduct the Household Activity Survey.[9] The survey firm purchased from a national sampling service a random probability sample of telephone exchanges from which to recruit households in each geographic strata. Therefore, each household with a telephone had an equal probability of being included in the sample, whether or not the telephone number was listed.[10]

Data collection for the Household Activity Survey included the following steps: (1) recruitment of household by telephone; (2) mailing survey packets to participating households; (3) reminder calls to participating households on the day before their designated travel days; and (4) retrieval of data via telephone interviews after the second designated travel day.

Development of a Database for the Mode Choice Model

The first step was to extract from the household activity survey only those observations that result in trips that are valid for this study. Of the survey's 76,939 trips, 25,277 (about one-third) were designated as work trips (home-based work trips, non home-based work trips, and college trips). Of these, 2,606 ended at a destination within the Portland CBD[11] (see map 1). Of these, 843 trips take place during the weekday morning peak travel period. Of those, 584 trips are made by solo drivers, carpoolers, or transit riders. In the end, 523 trips are used to develop the mode choice model after 45 trips are excluded because of missing data.

Descriptive statistics, correlation, and cross-tabulation document the general findings in the mode choice analysis. The following tables show the demographic distribution of those who park free and those who pay to park.

Table 3 lists the mode split for all commuters to the Portland CBD during the weekday morning peak determined from the household activity survey.[12] Of those commuters in automobiles, 82 percent are solo drivers, and 18 percent are in vehicles with 2 or more occupants. Slightly more than half of all commuters drive alone. This display of mode choice is typical of a large CBD with healthy transit.[13]

Map 1
Portland, Oregon CBD
Study Area (in dark gray)

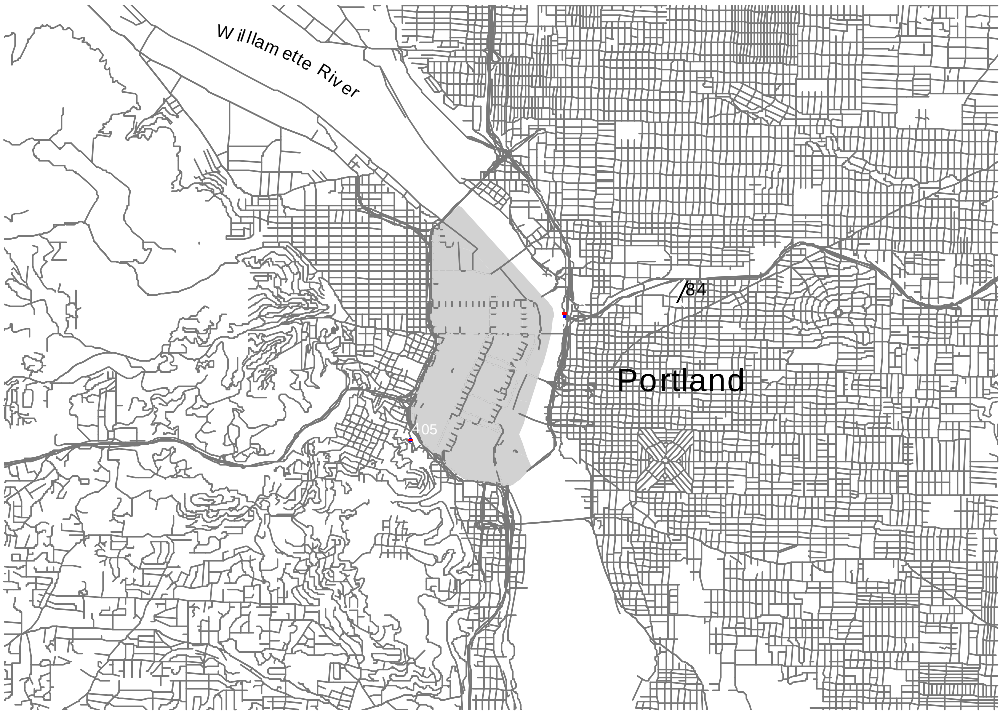


Table 3 Sample Mode Distribution for Commuters to Portland CBD Weekday Morning Peak

Mode	Percent of Commuters
Drive alone	50.9 %
Carpool	10.8 %
Transit	
Bus	24.5 %
Light rail	3.4 %
Walk	8.3 %
Bicycle	2.1 %
Sum	100.0 %

I now turn to the incidence of free parking among commuters as determined from the household activity survey. Among solo drivers, just over half of commuters park free regardless of their age, gender, or income (see table 4). The mode choice outcomes in table 4 closely match the findings from a separate study of the effects of employer-paid parking by Willson and Shoup (1990) for Los Angeles.[14]

Table 4 Free Parking vs. Paid Parking for Solo Commuters, Carpools and Transit Riders

Mode	Commuters
Drive alone	54 %
Carpool	14%
Transit	32 %
Total	100 %

53 % of Commuters Park Free

47 % of Commuters Pay to Park

In Portland, those who drove to work reported the actual price paid for parking if they did not park free, and those who rode transit reported the amount they *would have* paid to park (had they driven) if there would have been a parking charge. The average price paid to park among the sample group is $2.00 per day, with a range from $0 to $9. However, the average price paid to park among those who did not park free is $5.40 per day.

The price paid to park varies among commuters who arrive at the CBD by various modes. Table 5 lists the average daily parking price paid by those who did or would have had to pay to park their cars;[15] commuters in single occupant vehicles (SOVs) paid $5.17 per day, commuters in carpools paid $7.66 per day per vehicle (or $3.33 per commuter with a carpool occupancy rate of 2.3), and transit riders paid $6.47 per day. Transit riders had the highest average daily parking charge and paid an average of 25 percent higher than those who commuted in SOVs.

Table 5 Daily Parking Cost for Commuters to the Portland CBD

Mode	Daily parking price
SOV	$5.17
Carpool*	$7.66 per vehicle
	$3.33 per commuter
Transit	$6.47

** Assumes carpool occupancy rate of 2.3, the average rate for commuters to the CBD (during the weekday morning peak period) determined from the 1994 Portland Household Activity Survey.*

I can also compare this study's mode choice outcomes with data from the NPTS. Mildner et al. (1998) found that only 7.7 percent of drivers paid to park at work (n=44) although 50 percent of respondents indicated that they lived within 1/4 mile of transit (bus and light rail). Mildner et al. (1998) define Portland as a transit-accommodating city, where congestion costs are high and transit ridership may be higher-than-average.[16] There are no minimum parking requirements imposed in the Portland CBD, but there are parking maximums. In the Portland CBD, 10 percent of parking is publicly owned and the maximum parking meter rate is 90¢ (Mildner et al. 1998).

I now consider the distribution of free parking by occupation, using occupational status as a proxy for income. Occupation classifications from the household activity survey are collapsed into two categories: managerial/ professional and all others (see table 6).

Table 6 Free Parking and Paid Parking by Occupation Type

	Free parking	**Pay to park**	**Total**
Managerial/professional	30 %	28 %	58 %
All other occupations	22 %	20 %	42 %
Total	52 %	48 %	100 %

Commuters in managerial and professional occupations (who constitute the majority of commuters to Portland's CBD) are only slightly more likely to receive free parking than commuters in other occupations.

Finally, I consider the effect of the daily price of parking on mode choice decision (see table 7). The majority of commuters (62.8 percent combined) in single occupant vehicles, in carpools, or on transit *did* or *would have* received employer-paid parking.[17] There is no pattern evident in the relationship between daily parking charge and mode choice among those who parked free and those who paid to park.[18]

Table 7 Effect of Parking Cost on Mode Choice

	Mode share		
Daily Parking Cost	**Solo driver**	**Carpool**	**Transit**
$0	58 %	18 %	24 %
$1	35 %	63 %	2 %
$2	77 %	18 %	5 %
$3	58 %	5 %	37 %
$4	43 %	11 %	46 %
$5	61 %	3 %	36 %
$6 or more	49 %	4 %	47 %
Total	54 %	14 %	32 %

Development of a Probabilistic Choice Model

I assume that mode choice for the commute trip is an expression of preferences, and that the mode choice can be predicted if all of the relevant variables are known. A probabilistic prediction of choice is an expression of the probabilities that each of the available alternatives will be chosen. A model that relates these probabilities to the values of a set of explanatory variables is called a probabilistic choice model (Horowitz 1995).

I can use a multinomial logit model to estimate the influence of variables on the decision to choose a certain travel alternative.[19] I define three dependent variables: P_1 (the probability that a commuter chooses to drive an SOV), P_2 (the probability that a commuter chooses to carpool), and P_3 (the probability that a commuter chooses transit). By definition, the three probabilities sum to unity:

$$P_1 + P_2 + P_3 = 1$$

The fitted regression model is given by two equations:

$$\log\left(\frac{P_1}{P_3}\right) = a_a + b_{1a}x_{1+} b_{2a}x_{2+} b_{3a}x_3 + \ldots + b_{ia}x_i \qquad \text{(Equation A)}$$

$$\log\left(\frac{P_2}{P_3}\right) = a_b + b_{1b}x_{1+} b_{2b}x_{2+} b_{3b}x_3 + \ldots + b_{ib}x_i \qquad \text{(Equation B)}$$

In these equations, x_i (i = 1, 2, 3 ..... n) denotes the attributes of alternative (i) that are relevant to the choice being considered; a_a and are the intercepts, and $ß_a$ and $ß_b$ are the coefficients of equations a and b that are determined using PROC CATMOD in SAS programming language (see Horowitz 1995). The dependent variable is mode choice, and the explanatory variables are described in table 8.

Among the explanatory variables, I choose price variables that indicate the cost of commuting,[20] land use variables that consider the urban form surrounding the residence and its effect on mode choice, and household resource and taste variables that measure the characteristics of the household and the traveler. The model is constructed to reveal the individual and collective influence of the independent variables in affecting the consumption of three travel modes: SOV, carpool, and transit.

Table 8 Explanatory Variables Included in the Model

Variable	**Definition**
Price variables	
Daily parking cost	Cost (in dollars) of parking for an 8-hour workday.
Transit time	The difference (in minutes) between one-way transit travel and one-way driving travel.[21]
Transit time^2	The squared difference (in minutes) between one-way transit travel and one-way driving travel time.
Land use variables[22]	
Land use stratum	Dummy variable equal to 1 if the home TAZ is characterized as "not pedestrian friendly and not transit accessible" and 0 if the home TAZ is characterized as "pedestrian friendly and transit accessible."[23]
Transit access	Dummy variable equal to 1 if the residence is not within one-half mile of light rail and 0 if the residence is within one-half mile of light rail.
Household resource and taste variables	
Household size	Number of persons in household.
Number of vehicles	Number of vehicles in household.
Household income	Annual household income, bracketed into eight classifications.
Sex	Dummy variable equal to 1 for female and 0 for male.
Race	Dummy variable equal to 1 for Black/African American, Hispanic/Mexican American, Native American and Other and 0 for White Caucasian and Asian/Pacific Islander.
Occupation	Dummy variable equal to 1 for non-managerial/professional and 0 for managerial/ professional.
Age	Age of commuter in years.
Commuter subsidy	Dummy variable equal to 1 if the commuter does not receive a parking or transit subsidy and 0 if the commuter does receive a parking or transit subsidy.

Discussion of Variables

The first variable, "daily parking cost," indicates the actual price paid for parking by those who drove, and the price that transit commuters *would have* paid had they driven. By definition those commuters who get free parking at work have a daily parking cost of $0. For solo drivers, the price paid to park is a per-person parking charge, and to calculate the per-person parking charge in a carpool, the daily parking charge is divided by the number of members in the carpool. The transit time and transit time^2 variables are the absolute and squared difference between one-way transit travel time and one-way driving travel time. With the inclusion of these variables, the model takes into account the additional travel time that transit may require (but not the transit fare or vehicle operating costs); in this way the relative convenience of driving as opposed to using other modes is accounted for in the model. The two land use variables incorporate pedestrian connectivity and proximity to light rail transit in the model. The household resource and taste variables are based on demographic data reported by the respondents. The household variables which might have a bearing on mode choice were extracted from the household activity survey database.

Land use patterns relating to pedestrian amenities, as measured by the land use stratum variable, have been hypothesized to impact mode choice based on observed correlations. However, the inclusion of other relevant household resource and taste variables controls for their effects on mode choice. In general, the explanatory power of a model improves with the number of relevant independent variables, as well as the quality and quantity of data.[24] The next section focuses on modeling these multiple factors together, to test the hypothesis that each factor individually and all collectively do indeed influence mode choice for the work trip.

Model Results

This analysis concentrates on the mode choice decision for people who drove alone, carpooled, or rode transit and the variables that explain their mode choice behavior. Table 9 gives the results of the multinomial logit regression for mode choice (solo drive, carpool, transit) for each work trip on the factors thought to influence the travel mode& price, land use, and household taste and resource variables. The coefficients are estimated using the maximum likelihood method. The two models shown in table 9 are discussed below in turn.

Table 9 Estimate Multinomial Logit Model of Commuter Mode Choice

	Model 1				Model 2			
	Equation A		Equation B		Equation A		Equation B	
Independent Variable	Estimated Coefficient	sig	Estimated Coefficient	sig	Estimated Coefficient	sig	Estimated Coefficient	sig
Intercept	-0.7523	0.3101	1.5398	1.004	-1.9896	0.0000**	-0.8673	0.0625
Price Variables								
Daily Parking Cost	-0.2164	0.0000**	-0.4073	0.0000**	-0.1832	0.0000**	-0.3952	0.0000**
Transit Time	0.0152	0.0727*	-0.0312	0.0729*	0.0203	0.0058**	-0.0261	0.0173**
Transit Time^2	-3.8E-7	0.0729*	7.8E-7	0.0126**	-5.1E-7	0.0058**	6.5E-7	0.0172**
Land Use Variables								
Land Use Stratum	-0.1663	0.1623	-0.1348	.3788				
Light Rail Access	0.2155	0.6209	0.5352	0.2791				
Household Variables								
Household Size	-0.3143	0.0002**	0.0472	0.6388				
Number of Vehicles	0.7462	0.0000**	0.4658	0.0124**	0.5936	0.0000**	0.5608	0.0008**
Household Income	0.2008	0.0000**	0.1057	0.0291**	0.1349	0.0000**	0.0533	0.2704
Sex	-0.0770	0.4208	-0.1962	0.1309				
Race	-0.7602	0.0017**	-0.1563	0.6816				
Occupation	-0.4564	0.0000**	-0.4188	0.0020**	-0.4297	0.0000**	-0.3991	0.0025**
Age	-0.0198	0.0579*	-0.0574	0.0001**				
Commuter Subsidy	-0.7184	0.0000**	-0.2061	0.2129				

Model 1 (n=539, DF = 14, x^2 =1168, adjusted r^2 = 0.68, prob = 0.0000) Model 2 (n=539, DF=7, x^2 =1228, adjusted r^2=.069, prob - 0.0000)

** Significant at the 0.05 level * Significant at the 0.10 level

Model 1

Model 1 uses the daily parking cost to examine the mode choice effect of parking subsidies. The daily parking cost produces the expected negative coefficient (-0.2164 for equation a and -0.4073 for equation b), both with a high level of significance ($p = 0.0001$). Both transit time coefficients are significant at the 0.10 level, and one transit time^2 coefficient is significant at the 0.10 level (equation a) and the other is significant at the 0.05 level (equation b). The coefficients of the two land use variables (land use stratum and light rail access) are not significant. Both coefficients of only three household variables (number of vehicles, household income, and occupation) are significant at the 0.05 level. Each of the remaining five household variables (household size, sex, race, age, and commuter subsidy) have one of two coefficients that is not significant.

Model 2

More than ten alternative models were derived from Model 1 and tested but they are not included in this paper. Among the alternative models, Model 2 is the most robust (see table 9). Model 2 keeps six explanatory variables from Model 1 (daily parking cost, transit time, transit time^2, number of vehicles, household income, and occupation) and excludes the remaining seven variables. Both land use variables are excluded from Model 2, since the coefficients were not significant in Model 1. The coefficients of all variables in Model 2 are significant at the 0.05 level except for the intercept of Equation B (which is significant at the 0.10 level) and the Household Income of Equation B.

Discussion

Both multinomial logit models are robust in terms of the proportion of observed variation which they explain. For both models, the null hypothesis is rejected, and the explanatory variables are said to have significant value in explaining mode choice. Both models have r^2 values of around 0.70 and chi-square statistics that are significant at the 0.05 level, indicating that the independent variables explain a respectable amount of the variation in the dependent variable.[25] The modeling of individual-level data (not aggregated by socioeconomic factors or geography) helps to produce the low r^2 values.

In general, the coefficients predicted by both models follow expected patterns. The chief unexpected outcome is the insignificance in Model 1 of the coefficients for the land use stratum variable and light rail access variables. This outcome indicates that the likelihood of commuting by a particular mode is not influenced by high pedestrian connectivity nor a location near the light rail line.The models, therefore, show that the land use stratum and light rail proximity have no significant effect on mode choice. (This finding is consistent with the results of an analysis of San Diego household travel survey data by Crane and Crepeau 1998, in which the researchers found little role for land use in explaining travel behavior.) Furthermore, only 3.4 percent of commuters use light rail to get to the CBD (see table 3); this small sample makes it difficult to draw conclusions about the land use characteristics surrounding the homes of light rail commuters.

Let us consider in detail the multinomial logit equation estimated in Model 2. The coefficients for equation A indicate that higher transit travel time, more vehicles per household, and higher income increase the probability that a commuter will choose to drive in an SOV over riding transit. A higher daily parking cost, longer transit travel time^2, and a non-managerial occupation decrease the chance that a commuter will choose to drive in an SOV over transit.[26] The coefficients for equation B indicate that longer transit travel time^2, more vehicles per household, and higher income increase the probability that a commuter will choose to ride in a carpool over riding transit. A higher daily parking cost, longer transit travel time, and a non-managerial occupation decrease the chance that a commuter will choose to ride in a carpool over transit.

The coefficient estimates reflect the relative importance that commuters place on different attributes of the work trip. The presence of free parking or unsubsidized parking and the daily parking cost, the number of vehicles, and the household income have significant effects on the probability that a commuter will choose to drive alone to work.

Probability Predictions

Based on the above discussion of the two multinomial logit models of mode choice, Model 2 is selected as the preferred model. Model 2 has a high chi-squared statistic and an overall significance at the 0.05 level (p=0.0000). In addition, this model has the highest number of significant variables.

Model 2 is used to make probability predictions for the commuters to the Portland CBD. I accomplish this by determining the sensitivity of automobile commuting to daily parking cost. This is done by solving the multinomial logit equation for probability using a range of values for one particular variable and the variable's average value for all other variables using the estimated coefficients and intercept (see table 10). The mode choice probability ranges from a 62 percent chance of solo commuting with free parking to a 46 percent chance of solo commuting with a daily parking fee exceeding $6. The probability of commuting by carpool falls from 16 percent to 4 percent. At the same time, the probability of commuting by transit increases from 22 percent with free parking to a 50 percent chance of commuting by transit with a daily parking fee exceeding $6.[27] These probabilities are plotted in figure 1.

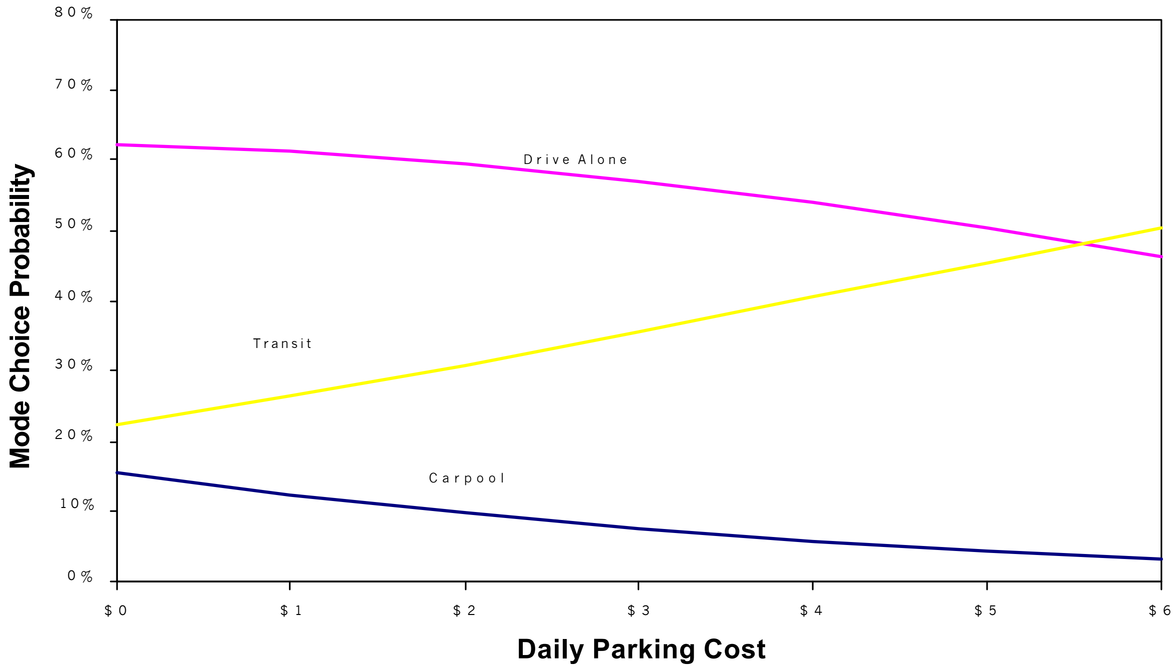
Table 10 Effects of Daily Parking Costs on Mode Choice Probability

	Mode Share		
Daily Parking Cost	**Solo Driver**	**Carpool**	**Transit**
$0	62 %	16 %	22 %
$1	61 %	12 %	27 %
$2	59 %	10 %	31 %
$3	57 %	8 %	35 %
$4	54 %	6 %	40 %
$5	50 %	4 %	45 %
$6 or more	46 %	4 %	50 %

In a multinomial logit model of downtown Los Angeles commuters, Richard Willson (1992) found a 70 percent chance of solo commuting with free parking and a 39 percent chance of solo commuting with a daily parking fee of $6. This finding indicates that free or inexpensive parking has a significant bearing on a commuter's choice of solo driving versus riding transit.[28]

The chief unexpected outcome is the decrease in probability of a commuter choosing to commute by carpool as the daily parking cost increases. To investigate this, I plotted the actual mode choice and daily parking cost of commuters in the data set alongside the model predictions, and found that in this data set fewer commuters *actually* choose SOVs and carpools and more commuters choose transit as daily parking cost increases. Therefore, the model's counterintuitive mode choice results

Figure 1. Effect of Daily Parking Cost on Mode Choice Probability

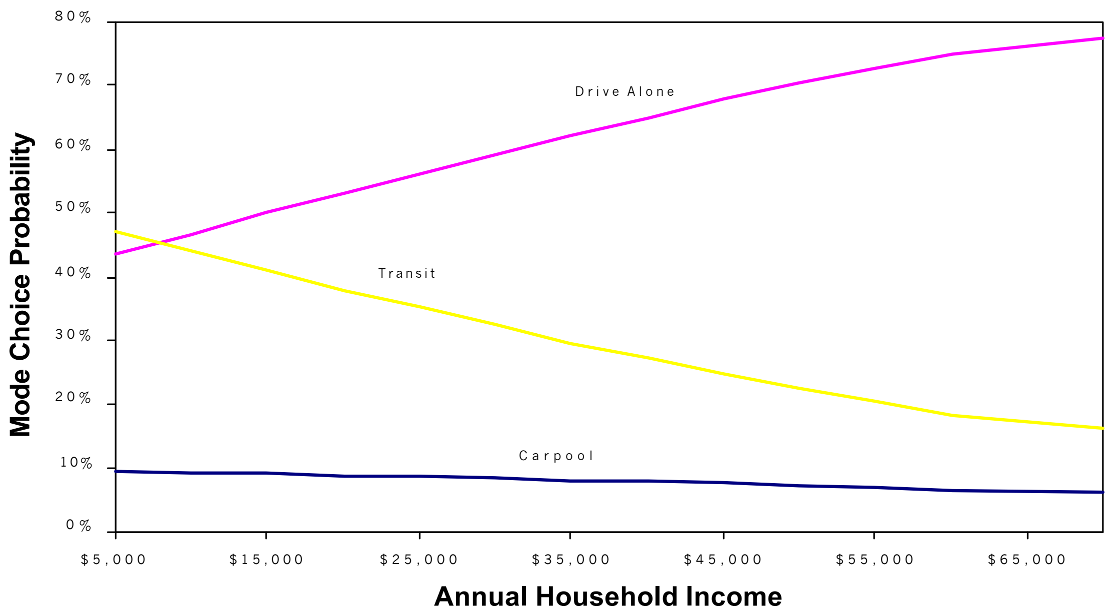


for carpool commuters is explained by actual mode choice of commuters.

The model can also be used to predict the probability of employees commuting in SOVs based on annual household income (see figure 2). I use the variable averages and the estimated coefficients and intercept. The average price paid to park is $2 per day. The probability ranges from a 44 percent chance of solo commuting with an annual household income of $5,000 to a 77 percent chance of solo commuting with an annual household income exceeding $70,000. At the same time, the probability of commuting by carpool falls from 9 percent to 6 percent. Commuters with an annual household income of $5,000 have a 47 percent chance of commuting by transit, and commuters with an annual household income exceeding $70,000 have a 16 percent chance of commuting by transit. Thus, commuters in higher-income households have a more inelastic demand for driving when there is a parking charge. The share of drivers who park free at work declines as their income increases. This does not mean that lower-income commuters are more likely to be offered free parking at work.

Instead, lower-income commuters who are not offered free parking are more likely to ride the bus, bicycle, or walk to work. Therefore, a greater share of lower-income drivers park free at work because lower-income commuters are less likely to drive to work if they have to pay for parking. This finding is useful in helping planners target certain demographic groups when they evaluate policies and programs to reduce solo commuting.

Figure 2. Effect of Household Income on Mode Choice Probability



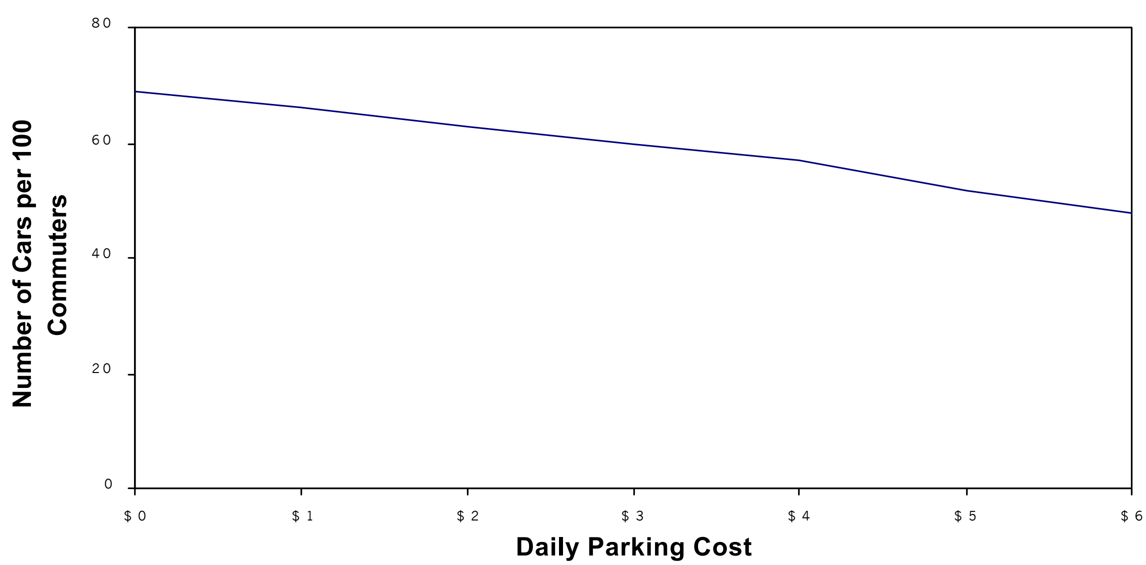
The model can be used to predict the change in the number of vehicles used for commuting (see table 11). With free parking, there would be 69 cars driven to the CBD (mode split is 62 percent SOV, 16 percent carpool, 22 percent transit) for every 100 commuters and with a daily parking charge of $6 there would be 48 cars driven to the CBD (mode split is 46 percent SOV, 4 percent carpool, 50 percent transit) for every 100 commuters. This relationship is shown graphically in figure 3. In other words, the mode choice model predicts that a daily parking charge of $6 in the Portland CBD would result in 21 fewer cars driven for every 100 commuters. This translates to a daily reduction of 147 VMT per 100 commuters and an annual reduction of 39,000 VMT per 100 commuters.[29] I use the change in the number of cars driven to work to estimate the price elasticity of demand for parking, which is shown in table 11.[30] As expected, people's demand for parking becomes more elastic as the daily parking charge increases.

Table 11 Effect of Daily Parking Cost on Number of Cars Driven to the CBD

Daily parking cost	Number of Cars				Number of cars per 100 commuters	Price elasticity of demand for parking at work
	Solo driver	Carpool	Transit	Total		
$0	334	38	0	372	69	- 0.02
$1	329	28	0	357	66	- 0.07
$2	318	23	0	341	63	- 0.12
$3	307	19	0	326	60	- 0.18
$4	291	14	0	305	57	- 0.41
$5	270	9	0	279	52	- 0.44
$6 or more	248	9	0	257	48	

Note: Based on the sample of 539 commuters in the mode choice model. The prediction for the number of cars driven by carpoolers assumes a carpool occupancy rate of 2.3.

Figure 3. Effect of Daily Parking Cost on the Number of Cars Driven by Commuters to the CBD



Conclusion

Using a household activity framework to evaluate mode choice is useful because detailed information is collected about each activity/trip. Especially important for this study is the fact that the Portland household activity survey collected information about the availability of free parking and the price of paid parking at the destination for drivers and nondrivers.

Only the commute to work was examined in this study's mode choice model. Because work trips tend to be longer in distance than many other trip types (such as household provisioning, recreational, social), commuters are less likely to substitute other modes for work trips. Commuters are also more likely to pay to park their cars when commuting to work than traveling to other destinations. For shorter trips, such as shopping trips, perhaps there is more opportunity for replacing auto trips with walking and bicycling.

The multinomial logit model of commuter mode choice produces two key findings. (1) Parking cost and the travel time by transit influence mode choice decisions for commuters. This suggests that raising the cost of parking at work sites and decreasing the transit travel time (by iproving service and decreasing headways) will reduce the percentage of people who drive alone to work. Of the non-policy variables, income and vehicles per capita have an effect on mode choice, but whether the commuter is male or female is unimportant. (2) Two land use variables are used in the mode choice model. They are the proximity of the commuter's residence to a light rail station, and the "pedestrian connectivity" of the streets and sidewalks surrounding the commuter's residence. Neither land use variable has a significant effect on mode choice. This finding supports the contention that urban form has little impact on mode choice decisions.

In study of travel and parking behavior, Mildner et al. (1998) found that cities with interventionist parking policies, high parking prices and limited supply, frequent transit service, and a high probability that travelers will pay to park are the most likely to have high transit ridership. From a policy perspective, the provision of free parking by employers contradicts policies designed to decrease solo driving and thus exacerbates the externalities associated with automobile use, such as traffic congestion and poor air quality.[31] The results of this study indicate that urban planners and transportation analysts will have the greatest success in influencing the mode preference of individuals (single occupant vehicle to carpool or transit) by charging commuters the true cost of parking or allowing commuters to increase their income by “cashing-out” their parking spaces when they choose to commute by another mode.[32]

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EndNotes

1.For discussion of the effect of employer-paid parking, see MacKenzie et al. (1992), Zupan (1992) and Willson and Shoup (1990). Willson and Shoup (1990) estimate that 90 percent of U.S. automobile commuters park free at work.

2.The activity survey included a stated-preference survey designed to analyze individual's reactions to possible urban design and Travel Demand Management (TDM) actions such as congestion pricing and the availability and price of parking. Although stated-preference modeling has been used extensively in market research and in long-distance travel demand modeling, such techniques are now only beginning to be applied for urban area travel demand analyses.

3.Households were recruited by telephone; person, vehicle, and household information were collected by survey staff at this time. Recruited household were then sent a packet of information. Two days before their assigned travel days, households were sent a reminder level. During the survey days, household members used activity recording sheets. (One reason for collecting two days' activity/travel data was to observe differences in travel behavior *within* households by day of week.) After the survey days, survey staff collected activity information from respondents using CATI (computed-assisted telephone interviewing); 20,161 households were contacted, and 4,451 household ultimately completed surveys.

4.Researchers use activity-based survey data to better understand the nature of the derived demand for travel. Travel is a derived demand because it is a means to an end, and the need to travel arises from the choice to conduct an activity out of the home.

5.Data was collected at the person, household, trip, and vehicle level, and all data files can be joined together using a unique sample number. The sample number can be located within a census tract or TAZ. In this way, several independent variables collected at different levels of analysis (zone based vs. household vs. individual) can be joined together.

6.The estimate of total households is based on 1990 Census STF-3 data and factored to 1994.

7.The 1000 Friends of Oregon (1993) created a measure of pedestrian access, known as PEF (pedestrian environment factor). Pedestrian access is defined as a mixture of the ease of street crossings, sidewalk continuity, topography and whether a neighborhood street network is primarily *cul-de-sac* or more open. Each category is scored on a scale from one to four (four being the best ranking), so each zone has a maximum possible score of 16 and a minimum of four. The higher the score, the more the zone accommodates non automobile travel. The study found that, as expected, residents in neighborhoods with higher density, proximity to employment, grid street pattern, sidewalk continuity, and ease of street crossing tend to make more pedestrian and transit trips, whereas residents of more distant, lower density suburban areas with auto-oriented land use patterns show extensive reliance on the automobile.

8.A stratum was created for park-and-ride users by recording license plate numbers at park-and-ride lots. Names, addresses and telephone numbers were obtained from the Department of Motor Vehicles, and the sampled households were recruited in the same manner as household in other strata.

9.The survey firm is NuStats International, Inc.

10.It was not possible to recruit households without telephones for this survey, which may under represent low-income households.

11.The study is limited to work trip that end at a location within the Portland CBD. Since this is the site in the metropolitan area likely to have the highest proportion of commuters who pay to park their cars, we are likely to see the effects of parking cost on commuter mode choice. For this study, Portland's CBD is designated as TAZs 1 through 16.

12.We can compare the mode choice distribution for Portland to national trends. Pisarski (1996) reports hat, excluding those who work at home, the mode share for commuting in the U.S. in 1990 were solo driver (75 percent), carpool (14 percent), transit (5 percent), and walk plus bicycle (4 percent).

13.Portland has, on average, 1.35 annual revenue hours of transit service per capita (Mildner et al. 1998).

14.Willson and Shoup (1990) present before-and-after data from five natural experiments in which employers who previously had provided free parking discontinue the practice. In four Los Angeles cases, they found that ending employer-paid parking reduced the SOV mode share by 81 percent (Mid-Wilshire), 49 percent (Warner Center), 19 percent (Century City), and 44 percent (Civic Center). Although I found a similar mode split in Portland as Willson and Shoup found in Los Angeles, Boarnet and Greenwald (2000) argue that travel diary data for Portland show higher frequencies of transit and walking trips than Southern California travel diaries, suggesting that urban form features in Portland might more easily allow alternatives to driving.

15.Respondents to the household activity survey who used a mode other than a vehicle for the trip were asked "Would you have had to pay to park if you went by car?"(Q11) [Yes/No] "How much would you have had to pay?" (Q11A) XX.X per Hourly/Daily/Weekly/Monthly/Semesterly (Q11ATIME). Respondents who used a vehicle for the trip were asked "Did you pay for parking?" (Q24) [Yes/No] "How much did you pay for parking?" (Q25) XX.X per Hourly/Daily/Weekly/Monthly/Semesterly (Q25TIME). The prices reported were converted to a daily parking cost.

16.The annual congestion cost is $330 per traveler computed from Schrank et al. (1990). Eight transit accommodating cities in the U.S. have an average solo driver share of 68.4 percent.

17.It is important to mention up front that one possible source of error is the notion that there is a difference between the two groups of commuters (those who pay to park and those who park free) that is not accounted for by the model specification.

18.This variable is likely to have survey respondent error. Transit riders were asked to report the price they *would have* paid to park if they drive, but they may not know this information accurately if they are non-drivers. Even drivers themselves may not know exactly how much they pay for parking. For example, some commuters may have their parking fees automatically billed or deducted from their salary.

19.See Ben-Akiva and Lerman (1985) and Harvey (1994) for studies using logit models for predicting mode choice.

20.Parking cost and travel time by transit are the only cost variables included in the final models; other costs (fuel cost, automobile running cost, etc.) are excluded.

21.Travel times are calculated for TAZ-centroid to TAZ-centroid by the Portland Metro travel network analysis based on ME2 modeling process. Inter and intrazonal A.M. peak period travel times on the highway and transit network were provided by Portland Metro and generated by its travel demand model. The difference between auto and transit times allows the model to include commuters' sensitivity to longer travel times by transit versus automobile.

22.Land use variables are available from Portland Metro's Regional Land Information System. This database is a set of GIS files containing information on census block groups, transportation analysis zones, streets and rail corridors.

23.Data *are* available on land uses at trip destinations as well as origins. However, all trips selected for the this study's mode choice model end in the CBD, where the built and natural environment is conducive to pedestrian activity and transit access is good. Therefore, we concentrate on land use at the trip origin to determine its effect on mode choice.

24.It is often the case with transportation models that some of the factors that influence travel decisions are unobservable or unavailable, making it impossible to fully explain travel behavior.

25.Although the models perform well, the process of transforming discrete variables into dummy variables (having a value of 0 or 1) that are suitable for the logit model may introduce error into the procedure.

26.Managerial jobs tend to pay higher than non-managerial jobs, and this expands or constrains a commuter's mode choice set.

27.The model predicts that with increasing daily parking cost there will be a greater shift among commuters from SOV to transit than from SOV to carpool. There is a high up-front cost of forming carpools, and commuters may find carpools less convenient because of reduced commuting flexibility and the lack of a car during the daytime for errands or emergencies.

28.Willson (1992) used data from a 1986 mode-choice survey of downtown office workers to estimate a multinomial logit model of mode choice and parking demand. He found that eliminating free parking would reduce the SOV share from 72 to 41 percent, increase the carpool share from 13 to 28 percent, more than double the transit mode share 15 to 31 percent, and reduce the number of cars that would be driven to work (cars used for SOV trips plus cars used by carpools) by 34 percent. The parking cost elasticity for the same equation is -0.27 for the SOV mode, and the cross elasticity for transit is 0.35.

29.Assumes an average roundtrip commute distance of 7 miles.

30.The elasticity calculations use the arc elasticity formula.

31.This study's inconclusive findings about the effect of land use on mode choice show that more research on the effect of urban form on travel behavior is needed before planners attempt to reduce congestion and air quality through changes in urban form. In addition, more research may be needed on the PEF land use strata developed by 1000 Friends of Oregon (1993) as an indicator of land use.

32.For a discussion of the costs and benefits of parking cash out, see Shoup (1994) and Shoup (1997).