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Land Use, Urban Design, and Non-Work Travel: Reproducing for Portland, Oregon, Empirical Tests from other Urban Areas

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Abstract: This paper replicates the research on non-work automobile trip generation and land use conducted by Boarnet & Crane (1999) and Boarnet & Sarmiento (1998) for the Portland, Oregon region. Additionally, new variables examining New Urbanist arguments are incorporated. The results suggest that any links between land use and non-work trip behavior act primarily by influencing trip costs, in terms of distances traveled and speeds achieved, rather than directly influencing the number of trips made. This analysis is consistent with Boarnet and Crane and Boarnet & Sarmiento, suggesting that this model is not sensitive to errors which might arise due to the unique characteristics of the urban area under review.

I. INTRODUCTION

Much has been written about the prospects for using land use policy to influence travel behavior. In this paper, we use travel diary data to test the link between non-work automobile trip generation and land use characteristics. The method and regression specifications employed here reproduce, as closely as possible, the analyses conducted in different parts of southern California by Boarnet and Sarmiento (*1*), Boarnet and Crane (*2*), and Crane and Crepeau (*3*). In this paper we use data from a 1994 Portland travel diary. This has two important advantages.

First, much in the literature suggests that the link between land use and travel is sensitive to both the empirical specification of particular hypotheses tested and possibly to the peculiar characteristics of the urban area being examined. By reproducing the same test on a new urban area, we extend the literature in ways that allows an examination of the nature of land use-travel behavior links across different places.

Second, the results from southern California were limited by the possibility that automobile trip generation in a heavily automobile dependent region might not be sensitive to changes in land use or urban design (*1, 2, 3*). While the authors gave reasons to think that southern California is an appropriate laboratory for an initial test of the sort reproduced here (*1*), ultimately it is necessary to examine land use-travel behavior links in places that have explicitly sought to exploit those links. Few places have so self-consciously sought to link land use and travel as Portland has. Furthermore, the travel diary data for Portland show higher frequencies of transit and walking trips than the southern California travel diaries used previously, suggesting that Portland might more easily allow alternatives to driving behavior. Thus, if urban form influences travel behavior, it seems sensible to test for that link in Portland.

The link between land use and transportation has been extensively studied in Portland, in the context of the LUTRAQ project, but there are important differences between the approach and methods used in LUTRAQ and those used here. The emphasis of the LUTRAQ modelling effort was on projecting future land uses and travel patterns (*4*). The land use-transportation model in LUTRAQ was a modification of conventional four-step models of travel demand estimation combined with a model that predicted future land use. Non-work automobile travel was handled in the LUTRAQ study by estimating automobile mode shares.

Here, the focus is on hypothesis testing, not prediction. We examine non-work trip frequencies -- essentially confounding the trip generation and mode split steps of the traditional four-step travel demand estimation process -- because we believe that a focus on the number of non-work car trips clearly illuminates the hypothesis that urban design can reduce the amount of car travel. Furthermore, because we focus on hypothesis testing, we adopt the model of individual travel behavior used in Boarnet and Crane (*2*). That model includes more individual socio-demographic and land-use variables than were used in the LUTRAQ effort, largely because LUTRAQ, like many prediction efforts, was focused on explaining as much variance as possible with relatively few variables. Here we focus instead on testing behavioral relationships between variables that are suggested by *a priori* theory. Neither effort -- hypothesis testing or prediction -- is either right or wrong. Both serve their purposes, and we simply wish to point out the ways that the exercise presented here differs from the analysis associated with the well known LUTRAQ project.

II. PREVIOUS RESEARCH

The link between land use and non-work travel has been most prominently argued within the New Urbanism and related schools of architecture and urban design (*5, 6*). While the goals and details of the New Urbanism are multi-faceted, the land use elements most often purported to be associated with reduced automobile use are grid-oriented streets, inviting pedestrian environments, mixed land uses that create short distances between residences and shopping or entertainment destinations, and sometimes parking restrictions or other policies intended to raise the cost of driving. Similarly, transit-oriented developments (TODs) are designed to cluster residences, employment, and shopping around mixed-use, pedestrian-oriented rail transit stations, all in an attempt to encourage persons to walk to the train rather than drive to their destination (*7*). The common philosophy in both schools of thought is the idea that urban design can influence travel behavior. The notion is intuitive, partly because land use has long been an input to travel demand estimation models. Yet the evidence on whether designs of the sort proposed by, for example, the New Urbanism, can influence travel behavior is still inconclusive.

The recent literature on urban design and travel behavior has been summarized elsewhere (*1, 2, 8*), so our here discussion will be brief. Many recent studies have found evidence that densities, mixed use development, street orientations, and the quality of the pedestrian environments are linked to automobile travel (*9, 10, 11, 12*). Yet other studies have either found evidence of somewhat weaker links or argued that the association between land use and travel behavior is more complex than is evident in many of the previous empirical tests (*13, 3, 1, 2*). Overall, the literature appears inconclusive, giving results that seem to hold for some variables in some urban areas but that often disappear or change when other data or methods are used.

The difficulty with the literature to date hinges on two shortcomings. First, the studies in the literature use a wealth of dependent variables, independent variables, and analytical techniques. For a discussion and an extensive review, see Boarnet and Crane (*14*). Second, there has been almost no effort to reproduce tests in different urban areas. It thus is difficult to generalize the results of any study. Here we continue to employ the specifications most recently developed in Boarnet and Crane (*2*). Those specifications are an attempt to link the empirical analysis to a behavioral framework, and to consistently examine a small set of alternative empirical approaches. The specifications in Boarnet and Crane (*2*) have already been tested on two data sets, for Orange County including parts of Los Angeles and for San Diego. Here we present results for Portland. Reproducing the same test on three urban areas provides what, to our knowledge, is the most systematic attempt yet to examine how links between land use and travel behavior do or do not vary across different places.

III. THE MODELS

Following Crane (*15*), we represent demand for non-work automobile trips as

$$N = f(p,y;\mathbf{S}) \quad (1)$$

where N = the number of non-work automobile trips taken by an individual p = the time cost (or price) of a non-work automobile trip

y = individual income

S = a vector of sociodemographic shift (or taste) variables, which will be defined later.

In general, travel cost (p in Equation 2) includes both money and time cost. However, our sample is limited to private automobile users who are faced with similar money costs. Since all travel diary respondents are from the greater Portland area, we assume that there are no important variations in fuel cost across persons in our sample. Note that this assumption is reasonable, since the greatest variation in fuel costs occurs across rather than within urban areas. Variations in other marginal costs of driving within the Portland area, such as intra-metropolitan differences in parking costs, were not available in the data. Hence the model is simplified to consider only the time cost of travel.

The time cost of travel varies across individuals depending on their respective values of time. Differences in individual time value are captured by income and other sociodemographic characteristics. Following Kitamura, et. al. (*16*), income squared (y^2) is included in the empirical model. Of the studies reviewed earlier, only Kitamura (*16)* gives any attention to the need to control for how the value of time spent driving will change as income levels change.This quadratic representation is intended to capture both the extent to which non-work trip-making is a normal good and the extent to which time spent driving is more valuable (and thus more costly) for persons with higher income.

Given the inclusion of prices (here, time cost) and income in the non-work car trip generation model -- standard practice in any application of the theory of consumer demand -- the tricky question involves how land use might enter into a specification like Equation 1. Following Boarnet and Crane (*2*), we test three alternative specifications.

Model 1: Price Variation that is Completely Determined by Observable Land Use Characteristics

Perhaps the differences in time costs of non-work trips can be completely explained by differences in land use patterns. In other words, land use might affect non-work automobile trip frequencies by directly affecting the price, e.g. time cost, of travel. This is shown below.

$$p = f(\mathbf{L}) \qquad (2)$$

where **L** is a vector of land use or urban design characteristics. Substituting Equation 2 into Equation 1 gives

$$N = f(\mathbf{L}, y; \mathbf{S}) \qquad (3)$$

The model in Equation 3 is a reduced form which reflects the assumption that differences in the time cost of travel are due to differences in land use and urban design at different locations. Yet if land use and design are measured incompletely, which is plausible given the difficulty of operationalizing and measuring the characteristics associated with, e.g., the New

Urbanism, there might be differences in the time cost of travel even after the land use variables are introduced into a trip generation regression. This suggests the next model.

Model 2: Include both Price Variables and Land Use Variables in the Trip Generation Regression

Both the price variable, p, and the land use variables, L, can be used in a regression equation, as shown below.

$$N_a = f(p, y,; \mathbf{L}, \mathbf{S})$$

The time-cost variable p can be broken down into two components, trip distances and trip speeds. These variables can be more easily linked to policy, since urban designs have been proposed with the explicit intent of, for example, changing automobile trip speeds (e.g. traffic calming) or changing trip distances (e.g. mixed land uses or more direct, grid-oriented, street patterns). The result of representing p by trip distances and trip speeds is shown below.

$$N = f(m, t, y; \mathbf{L, S})$$

where m = non-work trip distance

t = non-work trip speed.

Following Crane and Crepeau (*3*), we use the median of non-work trip distances (m) and non-work trip speeds (t) for each travel diary respondent.

Model 3: A Two-Step Procedure

A two-step procedure can be implemented by first regressing the price variables (each individual's median non-work trip distance and median non-work trip speed) on land use characteristics near that person's residence, as suggested by Equation 3 and shown below.

$$m = f(\mathbf{L})$$

$$t = f(\mathbf{L})$$

The predicted distances and speeds from that regression will, by construction, be uncorrelated with other determinants of trip prices. Those predicted values can then be used in the non-work car trip generation equation shown in Equation 1, to yield

$$N = f(\text{predicted } m, \text{predicted } t, y; \mathbf{S}) \quad (8)$$

Equation 8 is a reduced form that includes the effect of land use on trip prices (through the effect on distance and speed) and then the effect of prices on trip generation. This reflects rather directly the hypothesis that land use affects travel behavior through an effect on the (time) cost of travel.

IV. DATA

The Portland Travel Diary for 1994 is a two day travel diary collected for individuals in the three county area surrounding Portland Oregon. Information was collected on standard socio-demographic data, trip speeds and distances, and nature of related activities. Table 1 provides a list of variables used in the regressions presented here.

(***Insert Table 1 Here***)

The variables used are similar to those used in Boarnet and Crane (*2*) and Boarnet and Sarmiento (*1*). The income, ethnicity, gender, number of children per household, employment density figures and trip costs are similar to those used in the Boarnet and Crane (*2*) analysis. The instrumental variables used in Tables 6 and 7 are identical to those used in Boarnet and Sarmiento (*1*). In addition to these, two new variables were considered in this analysis.

The PCTGRID variable was created using GIS software by buffering within one quarter mile of the home location of each individual respondent, then summing the land area of all street sections within that buffer that were of a quadrilateral nature. That sum was then divided by the area of the quarter mile radius circle to get a proportion of the buffer area covered by a grid street pattern. This leads to a measure of street patterns that is similar to the one used in Boarnet and Sarmiento (*1*).

The PEFSCORE variable is the Pedestrian Environment Factor score for the transportation analysis zone in which the home of an individual respondent is located. The Pedestrian Environment Factor was originally developed by the 1,000 Friends of Oregon, a non-profit organization in the Portland region dedicated to monitoring growth management efforts, for the purpose of analyzing the quality of the pedestrian environment. The PEF score is a composite generated on four criteria: ease of street crossing, sidewalk continuity, street connectivity (grid vs. cul-de-sac) and topography (*4*). 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 greater the degree to which the zone accommodates non-automobile based travel.

V. RESULTS

Table 2 shows the results of fitting different versions of Models 1 and 2 on individual travel diary data and land use data from census tracts.

(***Insert Table 2 Here***)

Column 1 of Table 2 shows the results of an ordered probit regression for non-work car trip frequencies. (Ordered logit regressions were also implemented but are not reported here. The only difference in sign and significance between the ordered probit results reported in Tables 2 and 3 and the ordered logit results is that the coefficient on median trip speeds in column 3 of

Table 3 is significant at the 10% level using ordered logit, rather than the 5% level in the ordered probit regression.) The independent variables in Table 2 are socio-demographic characteristics of the individual traveller or their family. The results in column 1 verify some commonly observed relations in travel behavior – women make more non-work car trips, persons with children travel more, and non-work trip frequencies fall on work days (when less time is available for non-work travel). Cars per drivers in the household is unexpectedly negative, but that variable becomes insignificant in later columns of Table 1. In previous research, Boarnet and Sarmiento (*1*) found that cars per driver for the southern California travel diary was typically not significant. Whether or not cars per driver was included in the model had little effect on the land use and urban design variables in past studies (*2*, *1*). Though individuals appear to take more non-work car trips as they become older, without a more detailed examination of the age distribution of the travel diary respondents it is not clear to what extent this contradicts the expectation that the elderly would make fewer non-work driving trips.

The land use variables (in the **L** vector) are added to the regression in column 2 of Table 1. This is model 1 from Section III. None of the land use variables are significant at the five percent level. Median trip speed and distance are added to the model in column 3, and both have the expected signs, although median speed is significant at only the ten percent level. Persons with longer median trip distances make fewer non-work car trips, and persons with higher median trip speeds make more non-work car trips. The specification in column 3 most closely approximates the research reported in Boarnet and Crane for southern California (*2*).

In column 4 of Table 2, we take advantage of variables that were available in Portland but were not used in the earlier studies of southern California. Some of these variables, such as the pedestrian environment factor (PEF score), were specifically designed to capture aspects of urban design that facilitate travel by modes other than the automobile. Most of the variables added in column 4 are not significant, but the density of single family attached dwellings is negatively associated with non-work car trip generation at the ten percent (two-tailed test) level. Persons living in census tracts with higher single-family attached dwelling densities make fewer non-work car trips – something that is consistent with the travel hypotheses of, e.g., the New Urbanism.

In Table 3, we report the same specifications as in Table 2, but for Table 3 the land use (or urban design) variables are measured at the zip code rather than census tract level.

(***Insert Table 3 Here***)

Other scholars have suggested that links between land use and travel will vary from the fine-grained neighborhood to the larger regional level (*13*). Boarnet and Sarmiento found evidence that the influence of land use on travel behavior was more pronounced when land use variables were measured for zip codes than for smaller census tracts (*1*). Most of the relationships from Table 2 are unchanged in Table 3. Yet retail employment densities are negatively associated with non-work automobile trip frequencies in column 4 of Table 3. Persons living in zip codes with higher retail employment densities make fewer non-work car trips. To the extent that retail employment densities proxy for the mixed-use character of land use or the availability of nearby shopping opportunities, this is consistent with the hypotheses of the New Urbanism. Zip code population density is significantly positively related to non-work car trip generation in column 2 of Table 3. This is counter to the idea that high density areas are associated with less non-work car travel, but it is consistent with Crane's argument that the sign of the relationship between automobile trip generation and land use variables is often theoretically ambiguous (*14*, *17*). The results for zip code population density and zip code retail density both suggest that questions of geographic scale are important in examining the link between land use and travel behavior.

Tables 4 and 5 report the results of the two-step method from Model 3.
Recall that the two step method first regresses the price variables – median non-work trip speeds and distances – on all land use variables, and then uses predicted median speeds and distances as independent variables in the non-work trip generation model. Previous research (*2*) has established that the reliability of the two-step approach hinges crucially on having land use variables that predict median trip speeds and distances sufficiently well. For that reason, we use the full set of land use variables from column 4 of Table 2. The first stage regressions are shown at the top of Tables 4 and 5.

(***Insert Tables 4 and 5 Here***)

Census tracts with higher PEF scores and with higher single family (detached) and multi-family dwelling densities have shorter median non-work trip speeds. Because the PEF score is likely higher in more dense tracts, all of these results suggest that trip non-work car trip speeds are slower in more dense places. This is not surprising, as more dense, pedestrian friendly neighborhoods often have slower car trip speeds, either intentionally (e.g. through traffic calming) or because those neighborhoods are more congested. Looking at the determinants of median trip distance, tracts with higher population density and higher single and multi-family attached dwelling densities have shorter trip distances – again an intuitive relationship suggesting that density reduces trip lengths. The positive coefficient on the density of single family attached dwellings is unexpected.

Substituting predicted values from the first stage regressions into the ordered probit for non-work car trip generation shown at the bottom of Tables 4 and 5, predicted median non-work trip distance and speed both have the expected signs, although only median distance is statistically significant. This provides evidence that is similar to what was found in Boarnet and Crane (*2*). Land use characteristics might influence non-work trip generation, but the channel of influence appears to be through the influence of land use on the trip price variables. Recall that the specifications in Tables 2 and 3, which tested for more direct channels of influence, revealed hardly any significant links between the land use variables and non-work trip generation. The results in Table 4 suggest that land use, when it does affect non-work automobile travel, does so through the influence on the price variables, median speed and distance.

The results in Table 5, using zip code land use variables, are largely consistent with the results in Table 4. In Step 1 of Table 5, zip codes with higher density and PEF scores have slower median non-work car trip speeds. Zip codes with higher population density, PEF scores, and proportions of single family detached and multi-family housing have shorter trip distances. The predicted trip distances both have the expected sign in the non-work car trip regression in Step 2 of Table 5, but both are statistically insignificant (although median trip distance is significant at the 10% level.)

VI. RESIDENTIAL LOCATION CHOICE AND NON-WORK TRAVEL BEHAVIOR

Boarnet and Sarmiento (*1*) note that relationships between urban design characteristics and travel behavior, even when statistically significant, do not imply that urban design causes persons to change their travel behavior. Another possibility is that some persons prefer to travel in certain ways, and that those persons choose to live in neighborhoods that support their desired travel patterns. For example, persons who prefer to walk might live in dense, pedestrian friendly neighborhoods, while persons who prefer driving live in more car-oriented suburbs. Yet it would be shaky to infer from those associations that urban design can be used to get persons who prefer driving to forsake their cars. The difficulty is that persons might choose where to live in part based on how they wish to travel. If so, the regression results in Tables 2 and 3 do not correctly reflect how changing land use patterns might influence non-work travel.

To illustrate this problem, and a solution, we first simplify the model from Section III. Assume that the number of non-work automobile trips is approximately continuous, such that the number of non-work automobile trips is given by

$$N = a_0 + a_1'\mathbf{L} + a_2 y + a_3 y^2 + a_4'\mathbf{S} + u \qquad (9)$$

where u = the regression error term.

If persons choose residential locations (and thus land use patterns near their residence) based on unobserved preferences which are correlated with attitudes about driving, the variables in the **L** vector can be correlated with **u**, the error term in Equation 9. If that occurs, the least squares parameter estimates for the above equation will be biased and inconsistent. As in other situations where independent variables are correlated with the regression error term, a solution is to use instrumental variables.

Choosing instruments for **L** requires some consideration of the determinants of land use patterns near persons' residences. This in turn requires some consideration of residential location choice. A large literature has studied moving and residential location decisions. A brief summary of that literature is that equilibrium residential locations (and thus land use patterns near individual residential locations) are the result of matches between individuals (the choosers) and residential sites (the choice set) (*18, 19, 20*). Thus the residential location of an individual is a function of individual and location characteristics, shown below.

$$ResLoc_i = f(\mathbf{C}_i, \mathbf{A}_i) \qquad (10)$$

where $ResLoc_i$ denotes the residence location for person "i"

$\mathbf{C}_i$ = individual sociodemographic characteristics

$\mathbf{A}_i$ = characteristics of residential locations, including location-specific amenities such as school quality, the demographic composition of the surrounding neighborhood, and the age of the housing stock in the surrounding neighborhood.

The variables in (10), because they explain residential location choice, are potential instruments for the **L** variables in (9). Of the variables in (10), the individual characteristics in **C** are likely to be the same as the demographic variables in **S**, leaving only the non-transportation neighborhood amenities in **A** as allowable instruments. As in both Boarnet and Sarmiento (*1*) and Boarnet and Crane (*2*), we chose four non-transportation neighborhood amenities as instruments, listed below.

%BLACK: The proportion of the 1990 population which is black in the census tract or zip code area.

%HISPANIC: The proportion of 1990 tract or zip code population which is hispanic.

HousePre40: The proportion of 1990 tract or zip code housing stock which was built before 1940.

HousePre60: The proportion of 1990 tract or zip code housing stock which was built before 1960.

These demographic and housing stock variables are likely to be correlated with the land use patterns measured by **L**, but, because they describe amenities which are unrelated to transportation, are plausibly exogenous to the error term in Equation 9. For all instrumental variables regressions reported below, we measured the instruments at the level of geography which most closely corresponded to the geographic detail of the land use variables.

The results of using instrumental variables to correct for location choice are shown in Tables 6 and 7. In Table 6, the land use variables are measured at the level of census tracts, while in Table 7 the land use variables are measured at the level of zip codes. Ordinary least squares regressions are also reported in Tables 6 and 7 for comparison.

(***Insert Tables 6 and 7 Here***)

Land use variables are significant in two instances in the instrumental variables regressions in Tables 6 and 7. The single family and multi-family housing density variables are significantly positive at the zip code level in the instrumental variables specification in Table 7, suggesting that individuals who live in more dense neighborhoods take more non-work automobile trips. This is counter to the expectations of the New Urbanism and related schools of thought. Zip code retail employment density is significantly negative in the instrumental variables specification in Table 7. This suggest that persons who live in neighborhoods with higher retail employment density take fewer non-work car trips, which is consistent with the expectations of the New Urbanism. The broader pattern that the land use variables were more often significant in the instrumental variables regressions when compared with the ordered probit results (from Tables 2 and 3) is similar to what was found in earlier studies of southern California. In the southern California work, as in the research presented here, the land use variables were often not significant, but the few specifications with significant land use variables more often used instrumental variables regressions of the sort reported in Tables 6 and 7 (*1*, *2*).

VII. CONCLUSION

In this paper, we present results of empirical tests that are designed to reproduce in Portland, Oregon, as closely as possible, studies of the link between land use and travel behavior in southern California. Several lessons of those earlier studies are reinforced by this research. The link between land use and non-work automobile trip generation often appears weak, but in some instances a link is evident. In looking for such a link, geographic scale is crucial. In this research, land use is more commonly tied to non-work car travel when land use is measured at the zip code level, suggesting that the influence of the region's urban form might dominate neighborhood design decisions. The importance of zip code level land use variables is especially evident in the instrumental variables regressions in Tables 6 and 7. In the two-step models reported in Tables 4 and 5, the results suggest that land use, when it influences non-work car trip frequencies, does so by changing the price of travel.

All of those results echo the results found previously in southern California. The implication is that urban design is a tool to change the price of travel, and should be analyzed as such. For some trips, that price (or time cost) variation is tied to neighborhood land use characteristics, but the evidence for Portland and the earlier studies of southern California suggest that more often land use at a broader, zip code level, is what influences driving behavior. The implication for efforts to use urban design to influence travel are twofold. First, the fine-grained neighborhood focus of the New Urbanism might obscure regional land use characteristics that more frequently are associated with driving behavior. Second, when land use variables appear to influence non-work driving behavior, that influence appears to work through changes in the time costs (price) of travel. More careful attention to how particular urban designs affect non-work trip distances and speeds can help future transportation planners better anticipate the impact of specific land use and urban design changes on driving behavior.

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Table 1: Variable Names and Definitions

Dependent Variable

NWTRIPS	Number of non work automobile trips per individual within a household over two day travel diary period

Socio-Demographic Variables

AGE	Age of individual respondent
CARSPRDR	Number of cars per licensed driver in household
GENDER	Gender of individual (1=Female, 0=Male)
INCOME	Household income
INCOMESQ	Household income squared
KIDS	Number of children under the age of 16 per household
NUMEMPLY	Number of employed workers per household
RACE	Ethnicity of individual respondent (1 = white, 0 = non-white)

Regional Land Use Variables

POP90_SQ	Population density per square mile in 1990 census tract
RET94DEN	Density of retail employment within 1 mile of home location in 1994
ZPPOPDEN	Population density per square mile for ZIP code
ZIPRETDN	Density of Retail jobs per square mile in ZIP code in 1992

Neighborhood Level Land Use Variables

MFDENCT	Proportion of Multi-Family dwelling units per census tract in 1990.
MFDENZP	Proportion of Multi-Family dwelling units per ZIP code in 1990.
MLRC	Home is within 1/2 mile of Multnomah Light Rail Corridor (1 = Yes, 0 = No)
PCTGRID	Percentage of area in 1/4 mile buffer zone covered by grid format
PEFSCORE	Pedestrian Environment Factor score for home transportation analysis zone
SFADENCT	Proportion of Single Family Attached dwelling units per census tract in 1990
SFADENZP	Proportion of Single Family Attached dwelling units per ZIP code in 1990
SFDDENCT	Proportion of Single Family Detached dwelling units per censu tract in 1990
SFDDENZP	Proportion of Single Family Detached dwelling units per ZIP code in 1990

Trip Cost Variables

TDIST_ME	Median trip distance per individual
TRIP_SPE	Median trip speed per individual
WORKDAY	Variable for whether or not diary covered at least one work day (1 = Yes, 0 = No)

Instrumental Variables

PCTBLKTR	Proportion of Black persons living in census tract in 1990
PCTBLKZP	Proportion of Black persons living in ZIP code in 1990
PCTHSPTR	Proportion of Hispanic persons living in census tract in 1990
PCTHSPZP	Proportion of Hispanic persons living in ZIP code in 1990
TRCT1940	Proportion of housing in census tract built before 1940
TRCT1960	Proportion of housing in census tract built before 1960
ZIP1940	Proportion of Housing in ZIP code built before 1940
ZIP1960	Proportion of Housing in ZIP code built before 1960

Table 2: Original Ordered Probit Models for Portland Per Boarnet & Crane Format - Census Tract Level

	Socio Demographics		Socio Demographics & Land Use		Socio Demographics, Land Use and Trip Costs		Socio Demographics, Land Use, Trip Costs and Housing Characteristics	
Variable	Coefficient	Z	Coefficient	Z	Coefficient	Z	Coefficient	Z
gender	**0.2345360**	**8.642**	**0.2440977**	**6.828**	**0.2240559**	**6.004**	**0.2287237**	**6.114**
age	**0.0043431**	**5.233**	**0.0032435**	**2.949**	**0.0034162**	**2.990**	**0.0033906**	**2.962**
race	0.0320039	0.532	0.0933742	1.239	0.1349054	1.722	0.1400998	1.786
income	-2.17E-06	-0.738	-2.70E-06	-0.691	-9.63E-07	-0.238	-6.20E-07	-0.152
incomesq	3.88E-11	1.550	4.89E-11	1.469	3.56E-11	1.036	3.44E-11	0.993
kids	**0.1180690**	**8.199**	**0.0961006**	**4.901**	**0.0883564**	**4.301**	**0.0889585**	**4.309**
workday	**-0.3653357**	**-6.122**	**-0.3760997**	**-4.969**	**-0.3476300**	**-4.493**	**-0.3459018**	**-4.455**
carsprdr	-0.0756065	-2.518	-0.0363110	-0.850	0.0130134	0.288	0.0124606	0.275
numemply	-0.0280374	-1.335	-0.0386944	-1.459	-0.0433655	-1.587	-0.0398496	-1.451
pop90_sq			0.0000133	1.832	2.91E-06	0.382	1.99E-06	0.220
ret94den			3.87E-07	0.009	-0.0000168	-0.386	-0.0000574	-1.022
pctgrid			-0.0105992	-0.086	-0.0863299	-0.677	-0.0726323	-0.562
tdist_me					**-0.0514554**	**-10.500**	**-0.0523074**	**-10.492**
trip_spe					0.0026349	1.906	**0.0032411**	**2.235**
pefscore							-0.0035707	-0.270
mlrc							0.0969227	1.596
sfddenct							-0.0558661	-0.181
sfadenct							-1.8067100	-1.933
mfdenct							0.0719691	0.207
N		5595		3237		2990		2979
Log (L)		-14029.6700		-8085.3300		-7432.0716		-7400.3901

Note: Coefficients in bold are significant at the five percent level or greater.

Table 3: Original Ordered Probit Models for Portland Per Boarnet & Crane Format - ZIP Code Level

	Socio Demographics		Socio Demographics & Land Use		Socio Demographics, Land Use and Trip Costs		Socio Demographics, Land Use, Trip Costs and Housing Characteristics	
Variable	Coefficient	Z	Coefficient	Z	Coefficient	Z	Coefficient	Z
gender	**0.2345360**	**8.642**	**0.2454954**	**6.824**	**0.2262212**	**6.023**	**0.2301202**	**6.109**
age	**0.0043431**	**5.233**	**0.0032881**	**2.974**	**0.0033709**	**2.935**	**0.0033444**	**2.907**
race	0.0320039	0.532	0.0989275	1.308	0.1257939	1.600	0.1311790	1.662
income	-2.17E-06	-0.738	-2.63E-06	-0.669	-1.02E-06	-0.251	-7.23E-07	-0.177
incomesq	3.88E-11	1.550	4.91E-11	1.470	3.75E-11	1.086	3.47E-11	0.999
kids	**0.1180690**	**8.199**	**0.0949035**	**4.836**	**0.0877663**	**4.266**	**0.0900124**	**4.334**
workday	**-0.3653357**	**-6.122**	**-0.3970868**	**-5.195**	**-0.3736424**	**-4.780**	**-0.3814734**	**-4.865**
carsprdr	**-0.0756065**	**-2.518**	-0.0385602	-0.904	0.0089302	0.198	0.0071291	0.158
numemply	-0.0280374	-1.335	-0.0297436	-1.103	-0.0345053	-1.242	-0.0276004	-0.982
zppopden			**0.0000249**	**2.977**	0.0000147	1.667	0.0000129	1.302
zipretdn			-0.0000406	-1.326	-0.0000603	-1.923	**-0.0000897**	**-2.364**
pctgrid			-0.0166261	-0.138	-0.1224619	-0.978	-0.0841338	-0.653
tdist_me					**-0.0514392**	**-10.394**	**-0.0525686**	**-10.453**
trip_spe					**0.0027491**	**1.976**	**0.0033705**	**2.310**
pefscore							-0.0072172	-0.587
mlrc							0.1088040	1.755
sfddenzp							0.2695163	0.594
sfadenzp							0.0934422	0.073
mfddenzp							0.4783802	1.061
N		5595		3192		2947		2936
Log (L)		-14029.6700		-7973.5979		-7324.6800		-7293.9033

Note: Coefficients in bold are significant at the five percent level or greater.

Table 4: Two Step Method for Impact of Trip Costs on Non Work Trip Frequencies - Census Tract Level

Step 1: OLS Regression of Population Density and Housing Characteristics on Median Trip Speeds and Distances

	Dependent Variable			
	Median Trip Speed		Median Trip Distance	
	Coefficient	T	Coefficient	T
pop90_sq	-0.0002220	-1.922	**-0.0001318**	**-3.854**
ret94den	-0.0013219	-1.901	-0.0001525	-0.741
pctgrid	-1.352254	-0.824	-0.1561129	-0.321
pefscore	**-0.5558000**	**-3.258**	-0.0865786	-1.715
mlrc	-0.4888672	-0.637	-0.1451040	-0.639
sfddenct	**-15.18939**	**-3.850**	**-6.327724**	**-5.419**
sfadenct	4.610017	0.408	**11.41121**	**3.410**
mfddenct	**-14.49242**	**-3.260**	**-6.741709**	**-5.123**
Constant	**38.38758**	**10.257**	**11.59652**	**10.468**
	N	3428	N	3428
	F-Test	12.28	F-Test	19.77
	R^2	0.0279	R^2	0.0442
	Adj. R^2	0.0257	Adj. R^2	0.0420

Note: Coefficients in bold are significant at the five percent level or greater.

Step 2: Ordered Probit of Predicted Speeds and Distances on Non-Work Car Trips

Independent Variable	Coefficient	Z
gender	**0.2467208**	**6.895**
age	**0.0032203**	**2.927**
race	0.093619	1.242
income	-2.54E-06	-0.650
incomesq	4.64E-11	1.391
kids	**0.0946328**	**4.859**
workday	**-0.3783989**	**-5.006**
carsprdr	-0.0360778	-0.846
numemply	-0.0335391	-1.265
ptdistm1	**-0.1362370**	**-2.344**
ptripsp1	0.0289179	1.342
	N	3225
	Log (L)	-8051.5549

Table 5: Two Step Method for Impact of Trip Costs on Non Work Trip Frequencies - ZIP Code Level

Step 1: OLS Regression of Population Density and Housing Characteristics on Median Trip Speeds and Distances

	Dependent Variable			
	Median Trip Speed		Median Trip Distance	
	Coefficient	T	Coefficient	T
zppopden	**-0.0003439**	**-2.707**	**-0.0001843**	**-4.906**
zipretdn	0.0002131	0.481	0.0001611	1.230
pctgrid	-2.062288	-1.253	-0.5855843	-1.203
pefscore	**-0.6420334**	**-4.044**	**-0.1156218**	**-2.463**
mlrc	-0.7816475	-0.996	-0.2946721	-1.270
sfddenzp	-10.23591	-1.752	**-7.48625**	**-4.334**
sfadenzp	27.81872	1.707	9.001781	1.867
mfddenzp	-11.13287	-1.932	**-8.145463**	**-4.779**
Constant	**34.31127**	**6.316**	**13.01822**	**8.104**
	N	3379	N	3379
	F-Test	10.82	F-Test	17.42
	R^2	0.0250	R^2	0.0397
	Adj. R^2	0.0227	Adj. R^2	0.0374

Note: Coefficients in bold are significant at the five percent level or greater.

Step 2: Ordered Probit of Predicted Speeds and Distances on Non-Work Car Trips

Independent Variable	Coefficient	Z
gender	**0.2490004**	**6.909**
age	**0.0033071**	**2.991**
race	0.0992163	1.313
income	-2.24E-06	-0.570
incomesq	4.42E-11	1.317
kids	**0.0961334**	**4.910**
workday	**-0.4022050**	**-5.267**
carsprdr	-0.0385005	-0.902
numemply	-0.0229748	-0.847
ptdistm2	-0.1126472	-1.655
ptripsp2	0.0208595	0.816
	N	3180
	Log (L)	-7943.8431

Table 6: Comparison of OLS and Instrumental Variable Regressions for Non-Work Automobile Travel: Census Tract Level

	CT Density (OLS)		CT Density (IV)		PCT Grid (OLS)		PCT Grid (IV)		Employment Density (OLS)		Employment Density (IV)	
nwtrips	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T
gender	**0.7204422**	**7.548**	**0.7234789**	**7.575**	**0.7595197**	**6.222**	**0.7645790**	**6.226**	**0.7106379**	**7.444**	**0.7037423**	**7.303**
age	**0.0164856**	**5.638**	**0.0166085**	**5.675**	**0.0133895**	**3.573**	**0.0133657**	**3.546**	**0.0161691**	**5.527**	**0.0159619**	**5.402**
race	0.2174054	1.029	0.1982175	0.935	0.4043940	1.57	0.3924073	1.514	0.2045868	0.973	0.2351949	1.109
income	-6.74E-06	-0.648	-5.61E-06	-0.536	-8.16E-06	-0.615	-2.69E-06	-0.195	-7.88E-06	-0.758	-8.94E-06	-0.844
incomesq	1.09E-10	1.238	1.02E-10	1.146	1.40E-10	1.244	1.02E-10	0.879	1.17E-10	1.328	1.25E-10	1.391
kids	**0.3697190**	**7.279**	**0.3784572**	**7.354**	**0.3051106**	**4.571**	**0.2866660**	**4.201**	**0.3565551**	**6.973**	**0.3452822**	**6.271**
workday	**-1.0122810**	**-4.979**	**-1.0147280**	**-4.99**	**-1.0978060**	**-4.31**	**-1.1832090**	**-4.51**	**-0.9975607**	**-4.906**	**-0.9850368**	**-4.281**
carsprdr	-0.0502618	-0.467	-0.0357714	-0.33	-0.0257278	-0.175	-0.0080227	-0.054	-0.0664085	-0.616	-0.0828379	-0.742
numemply	-0.1220593	-1.656	-0.1143170	-1.543	-0.1633060	-1.824	-0.1672191	-1.856	-0.1304251	-1.768	-0.1418376	-1.873
tdist_me	**-0.1354356**	**-11.793**	**-0.1321587**	**-11.115**	**-0.1541143**	**-9.796**	**-0.1528175**	**-9.644**	**-0.1359329**	**-11.978**	**-0.1380648**	**-11.666**
trip_spe	0.0045630	1.857	0.0047505	1.928	0.0061002	1.35	0.0076802	1.647	0.0044669	1.825	0.0044672	1.816
constant	**6.7051330**	**17.208**	**6.5135820**	**15.182**	**6.8488300**	**13.701**	**6.2585060**	**9.818**	**6.7874560**	**17.811**	**6.9242340**	**15.418**
pop90_sq	-0.0000168	-1.109	5.91E-06	0.226								
pctgrid					-0.1684701	-0.416	2.2049880	1.355				
ret94den									**0.0002126**	**-2.165**	-0.0003551	-1.402
N		5074		5074		2990		2990		5080		5074
F-Test		29.20		28.86		18.39		18.07		29.51		29.04
Prob > F		0.0000		0.0000		0.0000		0.0000		0.0000		0.0000
R^2		0.0647		0.0643		0.069		0.0583		0.0653		0.0650
Adj. R^2		0.0625		0.0621		0.0652		0.0545		0.0631		0.0628

Note: Coefficients in bold are significant at the five percent level or greater.

Table 6 (Cont.): Comparison of OLS and Instrumental Variable Regressions for Non-Work Automobile Travel: Census Tract Level

	PEF Score (OLS)		PEF Score (IV)		MLRC (OLS)		MLRC (IV)		Housing Density (OLS)		Housing Density (IV)	
nwtrips	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T
gender	**0.7254906**	**7.524**	**0.7339616**	**7.598**	**0.7277464**	**7.63**	**0.7282920**	**7.271**	**0.7209377**	**7.554**	**0.7025615**	**7.159**
age	**0.0160008**	**5.427**	**0.0162986**	**5.516**	**0.0165126**	**5.653**	**0.0165509**	**5.658**	**0.0164301**	**5.614**	**0.0151423**	**5.003**
race	0.2413490	1.134	0.2144007	1.004	0.1894846	0.902	0.2066040	0.976	0.2346814	1.111	0.3357422	1.381
income	-7.61E-06	-0.726	-5.97E-06	-0.567	-6.26E-06	-0.604	-6.08E-06	-0.584	-5.68E-06	-0.547	-1.06E-05	-0.99
incomesq	1.21E-10	1.36	1.09E-10	1.218	1.08E-10	1.226	1.07E-10	1.188	1.06E-10	1.195	1.34E-10	1.479
kids	**0.3701904**	**7.245**	**0.3832456**	**7.416**	**0.3725231**	**7.386**	**0.3737179**	**7.158**	**0.3597221**	**6.993**	**0.2843031**	**3.428**
workday	**-0.9930752**	**-4.834**	**-0.9913335**	**-4.823**	**-1.0259300**	**-5.047**	**-1.0247780**	**-4.847**	**-1.0053630**	**-4.946**	**-0.9809101**	**-4.669**
carsprdr	-0.0621329	-0.551	-0.0366824	-0.322	-0.0368203	-0.343	-0.0359775	-0.33	-0.0623981	-0.577	-0.1594638	-1.036
numemply	-0.1384906	-1.854	-0.1317756	-1.761	-0.1144938	-1.559	-0.1156199	-1.571	-0.1354814	-1.828	-0.1995333	-1.838
tdist_me	**-0.1475232**	**-11.968**	**-0.1428815**	**-11.324**	**-0.1316412**	**-11.667**	**-0.1317694**	**-10.023**	**-0.1380403**	**-11.953**	**-0.1445682**	**-5.812**
trip_spe	**0.0078692**	**2.07**	**0.0085573**	**2.238**	0.0046706	1.909	0.0047553	1.924	0.0044331	1.806	0.0042500	1.617
constant	**7.1125310**	**15.736**	**6.5232870**	**11.548**	**6.5349290**	**17.742**	**6.5280670**	**15.72**	**7.8389080**	**10.478**	7.7995010	1.485
PEF Score	**-0.0576183**	**-2.381**	-0.0007225	-0.018								
MLRC					0.2867731	1.911	0.2768463	0.183				
Housing Density												
SFD Density									-1.1387290	-1.611	-0.1559010	-0.031
SFA Density									**-4.6773660**	**-2.011**	-0.1999910	-0.019
Multi-Family Density									**-1.4962590**	**-2.008**	-2.3526190	-0.372
N		4992		4992		5080		5074		5074		5074
F-Test		29.1		28.34		29.42		28.89		25.55		24.88
Prob > F		0.0000		0.0000		0.0000		0.0000		0.0000		0.0000
R^2		0.0655		0.0645		0.0651		0.0652		0.0660		0.0553
Adj. R^2		0.0633		0.0622		0.0629		0.0630		0.0635		0.0527

Note: Coefficients shown in bold are significant at the five percent level or greater.

Table 7: Comparison of OLS and Instrumental Variable Regressions for Non-Work Automobile Travel: ZIP Code Level

	ZIP Code (OLS)		ZIP Code (IV)		PCT Grid (OLS)		PCT Grid (IV)		Employment Density (OLS)		Employment Density (IV)	
nwtrips	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T
gender	**0.7294203**	**7.611**	**0.7284262**	**7.596**	**0.7595197**	**6.222**	**0.7749035**	**6.302**	**0.7254779**	**7.565**	**0.7140110**	**7.415**
age	**0.0165643**	**5.646**	**0.0165240**	**5.626**	**0.0133895**	**3.573**	**0.0133221**	**3.539**	**0.0162438**	**5.531**	**0.0157788**	**5.334**
race	0.1787121	0.849	0.1794577	0.852	0.4043940	1.570	0.3871173	1.499	0.1707540	0.811	0.1547407	0.733
income	-6.39E-06	-0.614	-6.64E-06	-0.636	-8.16E-06	-0.615	-7.35E-06	-0.537	-7.09E-06	-0.681	-8.69E-06	-0.831
incomesq	1.09E-10	1.230	1.11E-10	1.248	1.40E-10	1.244	1.40E-10	1.209	1.14E-10	1.283	1.26E-10	1.413
kids	**0.3752066**	**7.372**	**0.3734229**	**7.287**	**0.3051106**	**4.571**	**0.2982868**	**4.389**	**0.3620533**	**7.102**	**0.3417562**	**6.459**
workday	**-1.0683870**	**-5.207**	**-1.0675400**	**-5.202**	**-1.0978060**	**-4.310**	**-1.2167460**	**-4.645**	**-1.0566670**	**-5.148**	**-1.0359280**	**-5.028**
carsprdr	-0.0422064	-0.391	-0.0454118	-0.419	-0.0257278	-0.175	-0.0217751	-0.147	-0.0573751	-0.532	-0.0892674	-0.812
numemply	-0.0926941	-1.246	-0.0940983	-1.262	-0.1633060	-1.824	-0.1322707	-1.453	-0.1027645	-1.380	-0.1181889	-1.569
tdist_me	**-0.1329591**	**-11.498**	**-0.1337269**	**-11.289**	**-0.1541143**	**-9.796**	**-0.1540072**	**-9.695**	**-0.1352926**	**-11.869**	**-0.1392917**	**-11.899**
trip_spe	**0.0047942**	**1.952**	**0.0047594**	**1.935**	0.0061002	1.350	0.0067116	1.443	0.0047102	1.915	0.0046169	1.874
constant	**6.5802840**	**16.813**	**6.6223650**	**15.923**	**6.8488300**	**13.701**	**6.7096980**	**10.741**	**6.7143310**	**17.886**	**6.9496510**	**17.071**
zppopden	1.37E-06	0.071	-4.85E-06	-0.171								
pctgrid					-0.1684701	-0.416	0.5723767	0.373				
zipretdn									-0.0001281	-1.831	**0.0003654**	**-2.099**
N		5032		5032		2990		2947		5027		5026
F-Test		29.01		28.77		18.39		18.13		29.23		29.03
Prob > F		0.0000		0.0000		0.0000		0.0000		0.0000		0.0000
R^2		0.0649		0.0648		0.0690		0.0690		0.0654		0.0633
Adj. R^2		0.0626		0.0626		0.0652		0.0652		0.0632		0.0610

Note: Coefficients in bold are significant at the five percent level or greater.

Table 7 (Cont.): Comparison of OLS and Instrumental Variable Regressions for Non-Work Automobile Travel: ZIP Code Level

	PEF Score (OLS)		PEF Score (IV)		MLRC (OLS)		MLRC (IV)		Housing Density (OLS)		Housing Density (IV)	
nwtrips	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T
gender	**0.7254906**	**7.524**	**0.7400684**	**7.629**	**0.7277464**	**7.630**	**0.7016874**	**6.879**	**0.7256634**	**7.569**	**0.7601137**	**7.697**
age	**0.0160008**	**5.427**	**0.0162491**	**5.483**	**0.0165126**	**5.653**	**0.0166820**	**5.620**	**0.0161802**	**5.509**	**0.0164098**	**5.453**
race	0.2413490	1.134	0.2120341	0.992	0.1894846	0.902	0.1603419	0.749	0.1783687	0.847	0.0968356	0.447
income	-7.61E-06	-0.726	-6.74E-06	-0.639	-6.26E-06	-0.604	-5.59E-06	-0.529	-6.97E-06	-0.668	-1.02E-05	-0.953
incomesq	1.21E-10	1.360	1.17E-10	1.305	1.08E-10	1.226	9.49E-11	1.041	1.15E-10	1.299	1.15E-10	1.270
kids	**0.3701904**	**7.245**	**0.3809822**	**7.348**	**0.3725231**	**7.386**	**0.3872318**	**7.284**	**0.3549198**	**6.876**	**0.4088937**	**6.338**
workday	**-0.9930752**	**-4.834**	**-1.0459760**	**-5.042**	**-1.0259300**	**-5.047**	**-1.0177070**	**-4.720**	**-1.0562100**	**-5.146**	**-1.0666970**	**-5.110**
carsprdr	-0.0621329	-0.551	-0.0423190	-0.372	-0.0368203	-0.343	-0.0602784	-0.546	-0.0695868	-0.643	0.0409078	0.320
numemply	-0.1384906	-1.854	-0.1104377	-1.460	-0.1144938	-1.559	-0.0955039	-1.270	-0.1144388	-1.523	-0.0263106	-0.284
tdist_me	**-0.1475232**	**-11.968**	**-0.1438252**	**-11.368**	**-0.1316412**	**-11.667**	**-0.1392947**	**-10.325**	**-0.1367030**	**-11.647**	**-0.1035175**	**-5.069**
trip_spe	**0.0078692**	**2.070**	**0.0085784**	**2.237**	0.0046706	1.909	0.0045250	1.809	0.0046172	1.880	0.0044638	1.789
constant	**7.1125310**	**15.736**	**6.6362240**	**11.948**	**6.5349290**	**17.742**	**6.7640660**	**15.939**	**6.8938120**	**7.172**	-2.1033670	-0.499
PEF Score	**-0.0576183**	**-2.381**	-0.0096453	-0.245								
MLRC					0.2867731	1.911	-1.3576230	-0.864				
Housing Density												
SFD Density									0.0269323	0.027	**8.9745360**	**2.224**
SFA Density									-2.5271090	-0.822	19.8955900	1.625
Multi-Family Density									-0.6024381	-0.630	**9.3955390**	**1.955**
N		4992		4947		5080		5032		5032		5032
F-Test		29.10		28.28		29.42		28.18		25.24		24.56
Prob > F		0.0000		0.0000		0.0000		0.0000		0.0000		0.0000
R^2		0.0655		0.0653		0.0651		0.0432		0.0658		0.0394
Adj. R^2		0.0633		0.063		0.0629		0.0409		0.0632		0.0368

Note: Coefficients shown in bold are significant at the five percent level or greater.