USING STRUCTURAL EQUATIONS MODELING TO UNRAVEL THE INFLUENCE OF LAND USE PATTERNS ON TRAVEL BEHAVIOR OF WORKERS IN MONTREAL

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ABSTRACT

This paper addresses the relations between travel behavior and land use patterns using a Structural Equations Modeling (SEM) framework. The proposed model structure draws on two earlier models developed for Lisbon and Seattle which show significant effects of land use patterns on travel behavior. The travel behavior variables included here are multifaceted including commuting distance, car ownership, the amount of mobility by mode (car, transit and non-motorized modes), both in terms of total kilometers travelled and number of trips. The model also includes a travel scheduling variable, which is the total time spent between the first and last trips to reflect daily constraints in time allocation and travel.

The modeled land use variables measure the levels of urban concentration and density, diversity, both in terms of types of uses and the mix between jobs and inhabitants/residents, the transport supply levels, transit and road infrastructure, and accessibility indicators. The land use patterns are described both at the residence and employment zones of each individual included in the model by using a factor analysis technique as a data reduction and multicollinearity elimination technique. In order to explicitly account for self selection bias the land use variables are explicitly modeled as functions of socioeconomic attributes of individuals and their households.

The results obtained show that people with different socioeconomic characteristics tend to work and live in places of substantially different urban environments. But besides these socioeconomic self-selection effects, land use variables significantly affect travel behavior. More precisely the effects of land use are in great part passed thru variables describing long term decisions like commuting distance, and car ownership. These results point to similar conclusions from the models developed for Lisbon and Seattle and thus give weight to the use of land use policies as tools for changing travel behavior.

Keywords: Structural Equations Modeling, Transport and Land Use, Travel Behavior, Montreal

INTRODUCTION

Nowadays urban mobility is strongly supported by the massive use of automobiles, inducing important environmental, socioeconomic and territorial impacts, many of them perceived by the majority of policymakers as strongly negative. This perception originated the emergence of several competing policy proposals aimed at reducing these negative impacts. The three most important are: Policies that advocate the diffusion and use of new technologies for cars and fuels, policies that advocate pricing measures in order to change travel behavior, namely the internalization of transport costs, and policies that advocate the use of land use changes to influence travel behavior and levels of car use. Transport supply policies although quite relevant are not generally seen as competing with demand reduction policies. During the last few decades the debate between advocates of the two latter policies has been rather intense (for some examples of these see Newman and Kenworthy, 1989, Giuliano, 1989; Giuliano, 1995; Newman et al., 1995, Neuman, 2005, Gomez-Ibañez, 1991, Gordon and Richardson, 1997). Consequently, the study of the relations between land use patterns and urban form and travel behavior was the object of important attention from researchers from mainly Europe and North America (see also http://onlinepubs.trb.org/Onlinepubs/sr/sr298summary.pdf). Due to this continuous attention that spawned from the 1990s to today, important theoretical and methodological innovations were made.

The first quantitative models built to test the existence of these relations were aggregated models. Therefore this first generation of studies was subjected to several criticisms (Boarnet and Crane, 2001; Crane, 2000; Handy, 1996), namely, the fact that they had little behavioral basis. These criticisms, paved the way for the appearance of models using the individuals or households as units of observation and decision making. Two important innovations were the application of models based on the utility theory (Cervero, 2002; Handy, 1996). Within the framework of utility theory travel behavior is considered as a derived demand, because it arises from the necessity for people to perform different activities in different places (Van Wee, 2002). By this reasoning the land use patterns influence travel behavior by changing travel costs either in an absolute or relative way. This type of influence can occur both in long or short term decisions, as car ownership or mode or destination choice. The utility theory, considers within its framework both long term and short term decisions, reflecting the fact that long term decisions influence short term decisions by restricting the alternatives available (Miller, 2003).

Other recent methodological advances expanded the framework of utility maximization in the activity based approach which creates models of activity participation and thus derives travel as the means used to participate in activities. In this case the land use patterns are determinants of opportunities and restrictions, posed in the pursuit of activities (Handy, 2004).

These innovations also highlighted other shortcomings of the empirical models used in this area of research. These include, endogeneity between variables, self-selection (either by attitudinal and/or socioeconomic effects) and causality, and the type and scale of land use variables. Since self-selection is related with the importance and direction of the relations between travel behavior and land use patterns, it is closely connected with causality between them. Endogenous relations that occur between independent variables will distort the obtained results. For example, car ownership is an important intermediate link, between location decisions and travel behavior, therefore including it in a single equation model trying to ascertain the effects of land use patterns on travel behavior will result in biased results.

Related with causality and endogeneity there were also claims of self-selection, namely the fact that people tend to choose to live in the places that allow them to pursue their preferred behavior (Bagley and Mokhtarian, 2002). This leads to the fact that, at least there are some endogenous effects between land use variables characterizing the area of residence and individual or household characteristics. A more radical hypothesis asserts that self-selection could be itself responsible for the differences in travel behavior found for residents in different urban environments. Or in other words, the individual characteristics are the sole responsible factors for different travel behavior patterns and land use variables are acting only as proxy variables.

Self-selection can be due either to attitudes and lifestyles (Bagley and Mokhtarian, 2002;) or to socioeconomic attributes. The way they affect residential location could be different. Attitudes would act as push influences, thus acting as an incentive to people locating in the places which enable their desired lifestyles. Socioeconomic attributes might act in a different way, they could act as restrictions (e.g. income), they could be indicators of specific preferences due to the household specific needs (e.g. household composition or presence of children) or they could act as indicators to unobserved attitudinal variables, assuming that people with similar socioeconomic traits tend to share similar attitudinal aspects. A recent review on the self-selection issue (Cao et al., 2009) concludes, based on the reviewed studies, for the existence of self selection but also for the existence of non spurious effects of land use patterns on travel behavior.

The ways to control for this problem include the following approaches (Bhat and Guo, 2007, Cao et al., 2009): controlling for attributes that jointly influence both travel behavior and residential location; using instrumental variable methods; use longitudinal methods, use joint discrete choice models and use Structural Equation Modeling (SEM), among other techniques. SEM allows the parameterization of endogenous relations between variables, thus accounting for self-selection effects (Bagley and Mokhtarian, 2002; Golob, 2003b). SEM represents an evolution and a combination of two types of statistical methods, factor analysis and simultaneous equations models (Kaplan, 2000). In SEM variables could be either exogenous or endogenous (Golob, 2003a, b). These characteristics allow SEM to handle indirect and multiple relationships and also to study reverse relationships. By being a simultaneous equation system it also allows the joint modeling of a comprehensive framework of hierarchical relationships between long term decisions (e.g., house or employment locations), to medium (e.g., car or transit pass ownership) or short term decisions (e.g., number of trips, trips by mode and trip scheduling). Specific estimation algorithms of SEM allow the estimation of discrete and censored variables, thus allowing them to be used within the framework of utility theory (Golob, 2003a) and even to expand that and include censored variables. For a more detailed description and discussion of SEM see for example (Bollen, 1989; Kaplan, 2000; Schumacker and Lomax, 2004).

Another important issue is the measurement of variables describing land use characteristics. One of the most widely used is urban density, although some authors claim that density is not the most adequate variable, since it encompasses many diverse characteristics that could not be easily replicated by simply changing density (Boarnet and Crane, 2001). Nevertheless, Cervero and Muramaki (2010) when comparing 370 urbanized areas in the US found a strong elasticity between VMT and density. Other adopted land use variables include: mix of employees and residents, mix and diversity of land use categories, urban design measures, house characteristics, and accessibility variables. Related important issues are the multidimensionality of urban space, and the interconnections that exist between land use variables (Krizek, 2003; Stead and Marshall, 2001). The former of these issues is due to the necessity of having at the same time an important number of land use variables that could encompass the multidimensionality of urban space, and to the need for a small overall number of land use variables to achieve higher model parsimony. The interconnections and amplification effects that could exist between different land use variables means that they could present negligible effects when analyzed one by one and significant effects when included in more comprehensive indexes (Stead and Marshall, 2001). These problems prompted the use of data reduction techniques in the treatment of land use variables such as factor or cluster analysis, which allow at the same time the reduction of the number of variables and the maintenance of the levels of richness in the characterization of land use patterns (Krizek, 2003).

The model presented here incorporates the conceptual and methodological innovations discussed above. This is done by explicitly incorporating self-selection effects due to socioeconomic characteristics and extending their effects not just to the residential location but also to the work location. It also treats explicitly the relations between long term and short term travel behavior related decisions, by including the relative location of home and employment places, car ownership levels, the number and distance of trips by mode and the total time spent outside home. The land use variables included here are also wide in scope and include also accessibility and transport supply measures. The model structure replicates a previously developed model for the Lisbon Metropolitan Area (de Abreu e Silva et al., 2006) and the Seattle Metropolitan Area (de Abreu e Silva and Goulias, 2009) thus allowing comparisons.

CASE STUDY AND MODEL DESCRIPTION

The present model uses data from the 2003 large-scale Origin-Destination travel survey (OD) conducted in the Greater Montreal Area (GMA). The GMA is the second largest metropolitan area in Canada and the most important in the Quebec province with more than 3.6 million people living in an area of around 5,500 square kilometers (2003 OD survey). It allowed collecting data from 5% of the residing population (around 70,000 households and 170,000 people). These surveys collect attributes on households and people as well as all spatial-temporal features of the trips done by persons 5 years and older during one day of the week (phone interviews, one-day travel diary). Details on these surveys can be found at www.cimtu.qc.ca. In order to allow comparison with previous modeling experiences (Lisbon and Seattle), a subset of the total sample of workers (43,145) was randomly selected. Hence, 7,277 observations (workers) are used in the model presented here. The GMA is recognized for having one of the highest transit share in Canada at around 22% in the AM peak period and more than 50% for trips heading to the CBD (central business district) during this period. Actually, the area is characterized by an important CBD (important share of jobs) and a quite monocentric structure, enhanced by the spatial structure of the suburban rail network that mainly travels commuters between suburban regions and CBD during peak periods. It also has an important subway network (68 stations, 4 lines) that is the core of the transit system; it was recently extended and other extension projects are being studied. Due to the relatively monocentric structure of the region, many heavy spatial trends can be summarized using distance from CBD. Table 1 presents some key figures (in cumulative frequency distributions) of the area for various classes of distances.

Table 1 – Featured characteristics of Montreal with respect to distance from CBD

	Distance to CBD			
Proportion of :	<5 km	<10km	<15 km	<20 km
People	8%	42%	60%	73%
55 years and older	8%	49%	68%	81%
0 to 15 years old	5%	35%	52%	67%
Households	10%	48%	65%	77%
1 person households	17%	63%	79%	87%
Non motorized households	19%	71%	87%	94%
Cars	5%	33%	51%	67%
Transit trip	13%	64%	84%	94%
Trips	7%	40%	58%	72%
Non-motorized trips	13%	47%	63%	74%
	<5 km	5 to 10 km	10 to 15 km	15 to 20 km
Population density (people/km^2)	6700	5040	1675	715

These data confirm the differences in spatial distribution of population segments and features around the CBD:

- Higher concentration of 55 years and older, 1 person households, non motorized households and transit trips up to 10 km away from the CBD;
- Higher dispersion of children and cars, with higher proportion on the outer rings;
- The declining population density from the central zones to the suburbs.

Table 2 contains a selection of individual and household characteristics of the sample analyzed in this paper.

Table 2 - Sample travel behavior and socioeconomic characteristics

Variables		Average	Standard Deviation
Endogenous travel behavior variables	Time spent between first and last trips (h)	9.82	2.30
	Dist. traveled - car (km)	23.58	86.74
	Dist. traveled - transit (km)	6.42	17.32
	Dist. traveled - non-motorized (km)	0.20	1.24
	Nº trips - car	2.25	1.65
	Nº trips - transit	0.65	1.34
	Nº trips - non-motorized	0.16	0.63
	Number of cars in the household	1.56	0.88
	Log commuting distance	1.96	1.08
Socioeconomic exogenous variables	Age	40.82	10.89
	Gender (%)	0.56	0.50
	Household Income	75.55	39.91
	Household size	2.85	1.23
	Household with teenagers (%)	0.20	0.40
	Household average age	33.49	13.33
	Adults average age	35.05	12.10
	Number of workers	1.70	0.64
	Household with 2 members (%)	0.34	0.47
	Household with 1 member (%)	0.11	0.32

The proposed model structure analyses the relations among socioeconomic characteristics, land use patterns, relative residential and employment locations, car ownership and travel behavior. The proposed model structure guiding general specification, following the one developed for Lisbon is as follows.

- It is assumed that land use patterns surrounding the residence and employment areas are influenced by the socioeconomic characteristics of the individuals and their households;
- Both land use patterns and socioeconomic variables influence travel behavior of employed individuals (workers);
- This influence is assumed to be at least partly mediated by variables describing several travel behavior related decisions, which go from long term decisions to shorter term ones;
- These variables include: the distance between employment and residence locations (commuting distance) and car ownership, considered as being longer term decisions which influence shorter term decisions such as the number of trips and distance

travelled daily by mode and the time spent between the first and last trips, corresponding to the height of Hägestrand prism in time geography;

- Land use variables are also allowed to be influenced by travel behavior variables, thus encompassing possible effects due to the fact that travel behavior is one of the visible outcomes of individual preferences and also the feedbacks due to the information that individuals have about optimal shorter term decisions (Domencich and McFadden, 1975)

The model's general structure is presented in Figure 1. The overall structure used in the Lisbon and Seattle models are the same. The main differences between this and those models are related only with the presence or absence of specific variables, since the used data was not specifically collected for these studies.

Figure 1 here

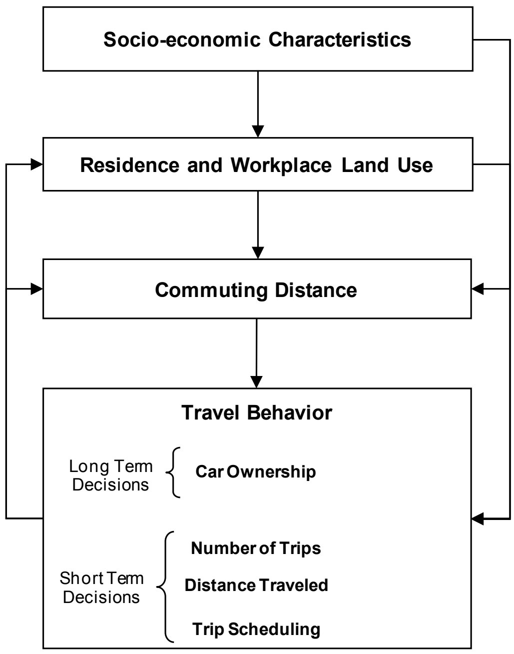

Figure 1 - Model general structure

The socioeconomic variables used in the model include: gender, age, household total annual income, household size, average age of the household, number of workers in the household, average age of the adults in the household, households with only one or two individuals and households with at least one teenager (1 if the household contains adults and at least one teenager, and 0 otherwise). The created land use variables were measured at the TAZ (traffic analysis zones) level in which the place of residence and employment of each individual respondent, labeled as home and work respectively.

The land use variables included a global population density (considering both inhabitants employees and students), the mix of land uses, percentage of urbanized area in each TAZ, and a compactness index. The compactness index corresponds to the quotient between the perimeter of the built area and the circumference of a circle with an equal surface. The distance of each TAZ to Montreal CBD was also included, and an entropy indicator was built. This entropy indicator measures the diversity balance between seven different categories of land uses, and it was first used by Cervero and Frank and Pivo (Kockelman, 1996). Finally, accessibility and transport supply variables were also created. These include accessibility indicators of both transit and car (using the gravitational accessibility approach), road supply density (km of roadways/person in each TAZ), the percentage of people at less than 500 meters from a subway and at less than 1 kilometer from a freeway node. All of these variables were reduced to 7 factors (using principal components) characterizing both the residence and employment locations (capturing 74% of the total variance). The factors and their defining variables together with their scores are presented in Table 3.

Table 3 - Land Use factors and their defining factor loadings (KMO = 0.74)

Land use factors	Most Important Variables	Loadings
Employment in a central, denser and accessible area	Accessibility by car (work)	0.914
	Accessibility by transit (work)	0.828
	Global density (work)	0.794
	Distance to the CBD (work)	-0.859
	Entropy (work)	0.427
	% people 500 m subway (work)	0.844
	% people 1km freeway node (work)	0.524
	% urbanized area (work)	0.786
Residence in a central, denser and accessible area	Accessibility by car (residence)	0.762
	Accessibility by transit (residence)	0.837
	Global density (residence)	0.885
	Distance to the CBD (residence)	-0.694
	% people 500 m subway (residence)	0.847
	% urbanized area (residence)	0.617
Employment in a denser area well served with roads	Global density (work)	0.521
	Km road/person (work)	0.906
	% people 1km freeway node (work)	0.598
Residence in a compact and small area and well served by roads	Compactness index (residence)	0.734
	Km road/person (residence)	0.651
	% urbanized area (residence)	-0.608
Working in a mixed and compact zone	Mix of land uses (work)	0.761
	Entropy (work)	0.411
	Compactness index (work)	0.722
Residence in a mixed and well served by freeways area	Mix of land uses (residence)	0.742
	% people 1km freeway node (residence)	0.812
Mix of land uses in the residence area	Accessibility by car (residence)	0.457
	Entropy (residence)	0.815

Clearly the first two factors present high scores in variables describing the concentration, centrality and accessibility of land uses, both for home and employment locations. For this reason they are named employment and residence in central, denser and accessible areas respectively. The third factor, related with the employment area, also has high loads on density combined with variables describing the levels of road supply. Thus is named Employment in a denser area well served by roads. The fourth factor is somewhat similar, albeit related with the residence area, and combines road supply with compactness and dimension of the urbanized area within the TAZ. It is named residence in a compact and small area and well served by roads. The fifth factor is associated with the levels of land use mix and compactness at the employment area, thus being named working in a mixed and compact zone. Next the sixth factor relates the accessibility to freeways with the mix of land uses in the area of residence and it is named residence in a mixed and well served by freeways area. The seventh and last factor is mainly associated with the levels of land use mix in the residence area and it is named mix of land uses in the residence area. These factors capture the most important dimensions of the home and work location characteristics and they are used as five dependent variables in a system that includes travel behavior variables. The method used here bypasses the need to identify choices in a discrete choice framework and the complicating issues of enumeration by converting the multiple dimensions of choice into 7 continuous variables.

ESTIMATION RESULTS DISCUSSION

The model estimation results are presented in the following way. First the direct effects between exogenous and endogenous variables (matrix gamma), then the direct effects between endogenous variables (matrix beta). The total effects between land use variables and the other endogenous variables are presented last.

The estimated model shows a good fit. The value of chi squared statistic is 71, with 211 degrees of freedom. The ratio between these two values is 0.34 which is an indicator of very good fit (Schermelleh-Engel et al., 2003; Jöreskog and Sörbom, 1993). Also the standard Bayesian criteria (AIC and CAIC) indicate that this model is superior either to the independence or the saturated models. Table 4 shows the matrix gamma coefficient estimates and their ratio to the estimated standard error.

Table 4 - Gamma matrix direct effects between endogenous and exogenous variables

	Age	Gender (man=1)	Househol d Income	Househol d size	d with teenagers	average age	of workers	d with 1 member	d with 2 members
Nº trips - car	0.2 36 *7.7*					- 0.1 37 -			- 0.0 20 -

	60					*11.983*			*2.869*
Nº trips - transit	-0.215 *-6.114*	-0.060 *-9.596*					0.220 *5.943*		
Nº trips - non-motorized			-0.170 *-24.342*		-0.005 *-3.102*				-0.031 *-11.744*
Number of cars	-0.154 *-4.634*	0.047 *5.380*	0.470 *10.766*		-0.026 *-3.496*		0.392 *8.281*		
Log commuting distance		0.076 *18.420*			-0.017 *-7.674*			-0.024 *-8.131*	
Employment in a central, denser and accessible area		-0.052 *-9.891*			-0.038 *-13.294*				-0.016 *-3.221*
Residence in a central, denser and accessible area	-0.251 *-7.926*		0.578 *17.852*	-0.123 *-5.325*		-0.192 *-7.602*	-0.108 *-12.254*	0.262 *20.432*	0.169 *11.809*
Employment in a denser area well served with roads		0.024 *4.363*			-0.008 *-3.393*		0.012 *2.387*		
Residence in a compact and small area and well served by roads					0.010 *4.488*		0.020 *4.156*		
Working in a mixed and compact zone		0.040 *7.2*							

		09							
Residence in a mixed and well served by freeways area			-0.060 *-4.485*		-0.034 *-13.594*				
Mix of land uses in the residence area		-0.007 *-1.233*							

Note: t-statistics in italic

These direct effects (gamma matrix) are in general in accordance with what would be expected. Older households and households with only two individuals tend to drive less with older individuals driving more. Older men use transit less, but having more workers within the household has a positive effect on transit trips. As the income rises people travel less by non-motorized modes, but also smaller households (with only two members), meaning that, due to the distribution of daily tasks among its members, tend to prefer faster transportation modes.

Households with higher levels of income and with more workers among their members tend to have higher car ownership levels which is also commonly accepted and in accordance to what was found in Lisbon and Seattle studies that used the same analytical method and model structure (de Abreu e Silva et al., 2006, de Abreu e Silva and Goulias, 2009). The commuting distance is higher for men, also a commonly accepted result, and smaller for the smallest households (with only one member).

The direct effects show that land use variables are influenced by the socioeconomic variables, thus revealing and capturing the existence of self-selection effects due to socioeconomic characteristics (i.e., different people reside in different places and both groups of variables influence travel behavior). Men and workers belonging to households with only two individuals and with teenagers tend to work outside central and denser areas. Younger, richer and belonging to small households, workers (almost a stereotype of modern urbanites) tend to live in central areas. Men belonging to households with a higher number of workers and without teenagers tend to work in denser areas well served with roads.

Workers in households with teenagers and with a higher number of workers have a stronger probability of living in compact and small areas and well served by roads. Most of them actually live in the near suburbs that possess lots of services and good transportation networks. Being a male worker tends to increase the probability of working in mixed and compact areas. Workers in households with lower income levels tend to live in mixed areas well served by freeways. The eastern part of the Island as well as near suburbs located at the north and south of the Island presents these attributes. Finally, the last land use factor is negatively influenced by the gender of the respondent, although not significantly, thus meaning that it is not well explained by the socioeconomic (x) variables present in the model. It was decided to leave this land use factor in the model, because it significantly influences travel behavior variables. Lack of significant explanatory variables may indicate an even spread of values across different sociodemographics. Table 5 presents the direct effects between endogenous variables.

Table 5 - Matrix beta direct effects among endogenous variables

	Dist. travelled - transit	Nº trips - car	Nº trips - transit	Nº trips - non-motorized	Number of cars	Log commuting distance	Employment in a central, denser and accessible area	Residence in a central, denser and accessible area	Employment in a denser area well served with roads	Residence in a compact and small area and well served by roads	Working in a mixed and compact zone	Residence in a mixed and well served by freeways area	Mix of land uses in the residence area
Time spent between first and last trips	-0.122 *-4.636*												
Dist. travelled - car		0.643 *24.956*											
Dist. travelled - transit			0.737 *38.707*										
Dist. travelled - non-motorized				0.873 *17.025*									
Nº trips - car			-0.485 *-32.588*	-0.239 *-26.945*		0.057 *3.680*							
Nº trips - transit				-0.123 *-20.186*	-0.506 *-14.139*	0.062 *5.481*	0.288 *27.949*		0.136 *16.014*				
Nº trips - non-motorized						-0.359 -	0.074 *15.3*	0.204 *27.0*		0.071 *12.1*	0.028 *4.98*	-0.021 -	-0.024 -

						33.680	*77*	*21*		*56*	*9*	*3.747*	*4.894*
Number of cars		0.134 *5.259*				0.085 *5.902*	-0.115 *-11.373*	-0.572 *-12.915*		0.087 *6.853*	-0.019 *-2.519*		-0.051 *-6.510*
Log commuting distance							0.148 *19.948*	-0.392 *-39.874*	0.047 *6.408*	0.128 *15.282*	0.091 *12.578*	-0.100 *-10.866*	
Residence in a mixed and well served by freeways area					-0.048 *-6.661*								

Note: t-statistics in italic

The direct effects between pairs of endogenous variables show in general the confirmation of the following:

- Land use variables affect directly travel behavior;
- Generally the relations between travel behavior variables are consistent with the expectation that long term decisions condition shorter term ones;
- Land use variables are also directly influenced by travel behavior variables;
- There is competition between transport modes, the use of one mode conditions the use of others;
- The distances travelled by mode are a direct function of the number of trips.

More specifically, the time spent between the first and last trips is negatively influenced by the distance travelled by transit. Also, the distance travelled by car, transit and non-motorized modes is only directly influenced by the number of trips on those modes, thus we don't have any evidence of people travelling less (in terms of numbers of trips) because they travel longer distances. The number of trips by car is negatively influenced by the number of trips using transit and non-motorized modes (e.g. walking, bicycle). It is also positively influenced by the commuting distance. The number of trips by transit is negatively influenced by the number of trips using non-motorized modes indicating the existence of competition between these types of modes. As expected, it is negatively influenced by the number of cars in the household, positively by the commuting distance and by two land use factors linked with the work place, employment in a central, denser and accessible area, and employment in denser areas well served by roads. These results show clear evidence that the common use of one mode of transport inhibits or even precludes the use of others, thus showing that competition exists between specific modes and for specific purposes. Regarding the effects of land use factors on transit it is possible to discern a pattern of transit use that is common in cities with strong rail transit network linking the suburbs with the city centre. People living in the suburbs and working in the city centre will use the rail system connecting the residence and employment locations thus explaining the positive effect of commuting distance on the number of transit trips.

The number of non-motorized trips is negatively influenced by commuting distance, and positively influenced by the following land use factors: employment in a central denser and accessible area, residence in a central denser and accessible area, residence in a compact and small area well served by roads and working in a mixed and compact zone. It is negatively influenced by the residence in a mixed and well served by freeways area and by the mix of land uses in the residence area. The fact that the effect of living in central area is much stronger than the one of working in the same type of areas corroborates the idea advanced earlier of people working in central areas and living in suburbs well served by rail, thus making the effect of this land use factor much stronger on the use of transit than on the non-motorized modes.

The number of cars in the household is positively influenced by the number of trips by car, this being an evidence of a feedback effect on an expectancy of positive disposition towards a specific type of behavior on a long term decision. This variable is also positively influenced by the commuting distance and by the residence in compact and small area well served with roads. It is negatively influenced by the land use factors associated with living or working in central and denser areas, with the mix of uses in the residence area and working in a mixed and compact zone. In addition, commuting distance is positively influenced by the land use factor employment in a central denser and accessible area, by the employment in a denser area well served with roads, by the residence in a compact and small area well served by roads and by working in a mixed and compact zone. It is also negatively influenced by the residence in a central denser and accessible area and by the residence in a mixed and well served by freeways area. Once again these results, in particular the fact that employment in a central denser and accessible area has positive effect on the commuting distance, corroborate the existence of an urban structure with a polarizing centre connected with mainly residential suburbs by a rail system.

Finally, there is one land use factor that is influenced by a travel behavior variable. Residence in a mixed and well served by freeways area is negatively influenced by the number of cars in the household. This means that people who prefer to own fewer cars tend to choose more central and denser locations.

The total effects between endogenous variables are presented in Table 6.

Table 6 Title?

	Dist. travelled - transit	Nº trips - car	Nº trips - transit	Nº trips - non-motorized	Number of cars	Log commuting distance	Employment in a central, denser and accessible area	Residence in a central, denser and accessible area	Employment in a denser area well served with roads	Residence in a compact and small area and well served by roads	Working in a mixed and compact zone	Residence in a mixed and well served by freeways
Time spent between first and last trips	-0.122	0.006	-0.093	0.010	0.047	-0.005	-0.032	-0.023	-0.013	0.004	-0.001	0.000
	-4.636	*3.383*	*-4.641*	*4.518*	*4.435*	*-3.786*	*-4.635*	*-4.606*	*-4.466*	*3.977*	*-2.444*	*2.384*
Dist. travelled - car		0.665	-0.322	-0.120	0.164	0.075	-0.110	-0.147	-0.040	0.015	0.000	-0.005
		28.259	*-19.225*	*-16.583*	*10.840*	*7.781*	*-15.545*	*-16.480*	*-10.737*	*6.013*	*0.111*	*-3.740*
Dist. travelled - transit		-0.052	0.762	-0.081	-0.386	0.041	0.264	0.188	0.105	-0.034	0.009	-0.002
		-5.237	*38.142*	*-17.651*	*-13.689*	*6.407*	*28.405*	*22.450*	*15.005*	*-7.867*	*2.869*	*-2.749*
Dist. travelled - non-motorized		0.000	0.000	0.873	-0.001	-0.313	0.019	0.301	-0.015	0.022	-0.004	0.013
		-2.240	*2.277*	*17.025*	*-2.474*	*-15.132*	*4.744*	*16.412*	*-5.912*	*4.162*	*-0.746*	*2.508*
Nº trips - car		0.034	-0.501	-0.186	0.254	0.116	-0.170	-0.229	-0.062	0.024	0.000	-0.008
		5.738	*-34.999*	*-20.791*	*12.660*	*7.930*	*-23.914*	*-25.599*	*-12.697*	*6.197*	*0.111*	*-3.756*
Nº trips - transit		-0.070	0.034	-0.110	-0.523	0.055	0.358	0.255	0.143	-0.046	0.012	-0.003
		-5.262	*5.737*	*-18.595*	*-13.939*	*6.514*	*45.180*	*25.781*	*16.456*	*-8.046*	*2.879*	*-2.762*
Nº trips - non-motorized		0.000	0.000	0.000	-0.001	-0.359	0.021	0.345	-0.017	0.025	-0.004	0.015
		-2.260	*2.298*	*2.248*	*-2.508*	*-33.681*	*4.865*	*50.289*	*-6.200*	*4.138*	*-0.750*	*2.541*
Number of cars		0.139	-0.067	-0.025	0.035	0.101	-0.125	-0.637	-0.004	0.101	-0.012	-0.010
		5.118	*-5.581*	*-4.933*	*5.819*	*7.037*	*-14.417*	*-14.392*	*-2.162*	*7.861*	*-1.469*	*-5.716*
Log commuting distance		0.001	0.000	0.000	0.005	0.000	0.147	-0.395	0.047	0.128	0.091	-0.100
		3.977	*-4.190*	*-3.874*	*6.388*	*4.774*	*19.848*	*-40.352*	*6.402*	*15.339*	*12.561*	*-10.863*
Residence in a mixed and well served by freeways area		-0.007	0.003	0.001	-0.050	-0.005	0.006	0.031	0.000	-0.005	0.001	0.000
		-4.031	*4.248*	*3.933*	*-6.665*	*-4.820*	*6.031*	*5.746*	*2.062*	*-4.978*	*1.426*	*4.639*

Note: t-statistics in italic

The total effects from the land use factors to the travel behavior variables show the existence of significant influences of land use patterns on travel behavior.

It is possible to see that the commuting distance is strongly and negatively influenced by living in a central and denser area and positively influenced by working in the same type of central areas and living in compact and small urban areas. This is possibly the impact of life in near suburbs. Also living in a mixed urban environment contributes significantly to reduce commuting distance. The results also show an evidence of positive feedback from the number of cars in the household and the number of car trips on commuting distance, which is passed by the effect of the land use factor residence in a mixed and well served by freeways area.

The results also show that living and/or working in central and denser areas as well as living in mixed areas have a negative effect on car ownership levels. Also living in small and compact areas well served by roads tends to increase car ownership levels.

Living and/or working in central and denser areas increases the number of trips using transit or non-motorized modes, and at the same time decreases the number of trips by car. These effects propagate themselves to the number of kilometers travelled by mode, thus increasing the policy relevance of land use patterns in reducing pollutant greenhouse gas emissions in transport sector. Moreover, living and or working in central areas reduces the total time spent outside home. In contrast, living in small suburbs well served by roads increases the time spent outside home.

COMPARISON WITH THE LISBON AND SEATTLE MODELS

One of the main objectives for building this model was to compare its results with two similar models built for the Lisbon Metropolitan Area (de Abreu e Silva et al., 2006) and the Seattle metropolitan area (de Abreu e Silva and Goulias, 2009). This comparison is presented mainly in terms of models' assumptions global structure and general trends in the estimation results since the variables used in these models are not the same due to different data availability in the other two metropolitan areas studied.

The global structure (Figure 1) was similar in all models with the following differences:

- The Seattle model did not include the number of kilometers travelled by mode;
- The Montreal model did not include pass ownership because that information was not available in the dataset used here.

Other more important differences in these models are related to the number and breadth of land use variables which in the Lisbon and Montreal models were vaster than in Seattle. However, in the Montreal and Lisbon models land use variables were mainly built at the zone level, whereas in Seattle a raster with grid cells of 750x750 metres, was used to compute several land use variables, while others were also measured at a zone level.

The results obtained in all models point to similar global conclusions. People with different socioeconomic characteristics and income levels tend to work and live in places of substantially different urban environments. Also some land use patterns (i.e., spatial choices) are influenced by travel behavior variables, which could be explained by the fact that travel behavior is among other things the visible result of personal preferences and lifestyles and people consider and select bundles of options. In all of these models car ownership influences just one of the land use variables.

But the main point here is that land use variables affect travel behavior in a significant way in every SEM estimated, thus giving additional weight to the argument of using land use measures as another available and effective policy tool to change travel behavior. Although the land use factors built for all these 3 models are different due to differences in the data available and the spatial distribution of the respondents, the first two land use factors represent basically working or living in central, denser and more traditionally urbanized areas, and therefore represent similarly structured living and working environments. Variables like density, distance from the CBD, mix and accessibility indicators have high loadings (with the exception of Seattle were variables of mix and accessibility were not available). Therefore and since the model results were standardized they can be compared, as shown in the following table (Table 7)

TABLE 7 – Total effects due to the first two land use factors

Travel behavior variables	Land use factors		
	Lisbon	Seattle	Montreal

	Residence in traditional urban areas	Working in traditional urban areas	Residence in a central and denser area	Employment in a central and denser area	Residence in a central denser and accessible area	Employment in a central denser and accessible are
commuting distance	-0.38	0.12		0.50	-0.40	0.15
car ownership	-0.07	-0.04		-0.10	-0.64	-0.13
pass ownership	-0.09	0.16	0.48	0.44	NA	NA
trips by car	-0.04	-0.11	-0.10	NS	-0.23	-0.17
trips by transit	0.12	0.17	0.05	0.41	0.26	0.36
trips non motorized	0.15	-0.05	0.07	0.13	0.35	0.02
km by car	-0.03	-0.09	NA	NA	-0.15	-0.11
km by transit	NS	0.18	NA	NA	0.19	0.26
km by non motorized	0.11	-0.04	NA	NA	0.30	0.02
NS - not significant at 5%	NA - not available					

The results presented in this table show that in general the direction of the effects is similar in all of these models.

The following general conclusions is drawn from the total effects of these three models:

- People living and working in central and denser areas tend to use more often non-motorized modes and transit and use less the automobile. Also these people tend to have lower car ownership levels in their households;
- Working in central and denser areas tends to increase the commuting distance, clearly a sign of the polarizing power that the centre of these metropolitan regions have, attracting people living in suburban and exurban areas. Also the total effects of working in central areas on the number of trips using transit are consistently high in all the three cases pointing to the importance that the centralization of employment has on transit use levels.

When comparing the Lisbon and Montreal model results (since in the Seattle model there were no variables describing the distances travelled by mode) it is possible to conclude that living and working in central and denser areas decreases significantly the number of kilometers travelled by car and increases the distances travelled by public transport. When looking at the total effects on the kilometers travelled using non-motorized modes there are some differences between Lisbon and Montreal. Whereas living in a central and denser area increases the distances travelled by non-motorized modes in both cases, working in the same type of area has opposite effects, in Montreal it also increases the distance travelled by non-motorized modes but in the Lisbon model the effect is contrary. These differences might be due to the specific spatial characteristics of both metropolitan areas as well as the differences in the public transport network and service.

But from the differences present in these three models it is possible to develop also interesting policy conclusions. Both in Montreal and in Lisbon the number of trips by car is a function of the number of trips by transit and non-motorized modes, which is evidence of competition among modes, whereas in Seattle there is no such evidence (de Abreu e Silva and Goulias, 2009). Since both Lisbon and Montreal have a more developed transit network which includes rail based services, whereas in Seattle the transit network is mainly based on buses it is possible to conclude that the level of public transport supply contributes heavily to make it a real and convenient alternative to car.

Also both in Seattle and in Montreal the total effects of car ownership on the commuting distance are positive whereas in Lisbon they are negative (although in Montreal this effect is quite small). In Lisbon these effects are passed via a direct effect of car ownership on commuting distance, which are attenuated by indirect effects via some land use factors (which have a negative impact on both car ownership and commuting distance). In Seattle there is a positive direct effect, which is amplified by land use factors associated with the supply of public transport. In Montreal there are no direct effects from car ownership to commuting distance. They are passed via an indirect effect of car ownership in one of the land use factors (residence in a mixed and well served by freeways area) and its magnitude is rather small. These results show that for people living in the suburbs and working in the centre of Lisbon, the public transportation system is a more convenient option when compared with Seattle and, in to a smaller degree, with Montreal. This fact points again to the importance of public transport supply levels together with land use patterns.

More precisely all these three models show that the effects of land use are in great part passed thru variables describing long term decisions like commuting distance, and car ownership. Once again we find that land use mix and density are important determinants of travel behavior, and tailoring policies to residents with specific environmentally friendly lifestyles can be an effective action. Moreover, public transportation combined with land use can give us the desired outcome of lower car use.

Regarding socioeconomic variables all models stress the impact that income has on travel behavior. All of them show that higher levels of income tend to have a positive effect on the car ownership levels. Regarding commuting distance the effects of income are positive both in Lisbon and in Seattle but negative in Montreal. This fact could be explained by the very strong direct effect of income in the land use factor residence in a central denser and accessible area, which is evidence of strong gentrification processes occurring in Montreal.

CONCLUSIONS

The main conclusions that could be drawn from the results of these three models are twofold. The first is that the model general structure holds in all of these three case studies thus giving robustness to the claim that it adequately describes the general relationships between travel behavior and land use patterns as well as the hierarchical decisions between long and short term decisions supporting forecasting model building that contains this type of hierarchy. The second is the fact that these results are strong evidence in favor of using land use policies as tools for changing travel behavior. But the implementation of land use policies should not preclude the use of other transport policy tools, like:

- Transport pricing policies – the strong total effects that household income has on car ownership and on car use, point to the need to consider policies able to tackle these effects;

- Public transport supply – the results point to the importance of heavy public transport supply associated with the correct land use patterns in increasing the levels of competition among modes thus contributing to reducing car dependence due to the lack of convenient alternatives.

Finally it should be added that the design of land use policies and its impact will be different depending on local circumstances and characteristics, as the results of these three models show the existence of similarities and differences between the three metropolitan areas. Thus implying that policies integrating transport and land use should be tailored to the specific characteristics of each metropolitan area as well as to the different population segments (in terms of combination of wealth, place of residence and work, and lifecycle stage) present in them. This is a much more complex process than current policy practice.

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