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

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ABSTRACT

This paper addresses the relations between travel behaviour and land use patterns using a Structural Equations Modelling (SEM) framework. SEM is a multi equation technique which is particularly suited for the study of complex relations, since it allows modelling the effects of land use patterns on travel behaviour while controlling for self selection bias and effects between endogenous variables. The proposed model structure draws on two earlier models developed both for Lisbon and Seattle which concluded for the existence of significant effects of land use patterns in travel behaviour. This paper is part of a research project which aims to compare results from different cities in North America and Europe, using the same modelling framework and similar travel behaviour and land use data sources.

The travel behaviour variables included here are multidimensional and include short term, medium term, and relatively long term mobility and related decisions. Regarding long term decisions the model includes variables such as home location. In the medium terms it includes variables such as car ownership. On the shorter term decisions the variables include the amount of mobility by mode (car, transit and soft modes), both in terms of total kilometres travelled and number of trips. The model also includes a trip scheduling variable, which is the total time spent between the first and last trips to reflect daily constraints in time allocation and travel.

The modelled land use variables measure the levels of urban intensity 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 ratios. 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 modelled as functions of socioeconomic attributes of individuals and their households. This makes spatial decision endogenous to the model system.

The model results for Montreal are discussed and compared with the results obtained using the Lisbon and Seattle datasets and previously published.

Keywords: Structural Equations Modelling, Transport and Land Use, Travel Behaviour, 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 policy proposals aimed atreducing these negative impacts. The three most important are: Policies that advocate the diffusion and use of new technologies, policies that advocate economic measures in order to change travel behaviour, namely the internalization of transport costs, and policies that advocate the use of land use changes to influence travel behaviour and levels of car use.

During the last 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 behaviour 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.. 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 behavioural basis. These criticisms, paved the way for the appearance of models using the individuals or families as units of observation and decision making. Other two important innovations were the application of models based on the utility theory (Cervero, 2002; Handy, 1996).

Within the framework of utility theory travel behaviour 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 behaviour 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, being 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).

However, the use of models based on the utility theory is plagued with difficulties. This is due to the fact that using Logit or Probit models doesn't necessarily implicate itself a utility theory based model since this type of model should reflect a theory based specification (Handy, 1996). Cervero (2003) also points out that most of these models have been badly specified - many important variables are missing and their functional forms may not correspond to human behaviour (e.g., infinite computing ability and optimizing behaviour).

These innovations also highlighted other shortcomings of the empirical models used in this area of research. One of them is the endogenous relations that occur between variables. For example, car ownership is an important intermediate link, between location decisions and travel behaviour. Related with this type of phenomena 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 they preferred behaviour (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 family characteristics. A more radical hypothesis asserts that self-selection could be itself responsible for the differences in travel behaviour found for residents in different urban environments. Or in other words, the individual characteristics are the sole responsible factors for different travel behaviours and land use variables are acting only as proxy variables of individual and family characteristics. One solution to unravel all these relationships is to formulate many equations representing all these choices and allow them to be correlated in their observed and unobserved components. In this way causal inferences of mutual influence can be measured by estimated correlation among the variables in the equations.

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 easy replicated by simply changing density (Boarnet and Crane, 2001). Other land use variables more generally used 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 reduction in the number of variables employed to capture the multidimensionality of urban space. 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).

One recent analytical innovation is key to the paper here, which is Structural Equations Modeling (SEM) (Golob, 2003a, 2003b). SEM allows the parameterization of endogenous relations between variables, thus accounting for self-selection effects (Bagley and Mokhtarian, 2002; Golob, 2003b). By being a simultaneous equation system it also allows the joint modelling 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). Relatively new estimation algorithms of Structural Equation Modelling 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.

All of these conceptual and methodological innovations are incorporated in the model presented in this paper with a structure that replicates a previously developed model for the Lisbon Metropolitan Area (Abreu e Silva et al, 2006) and the Seattle Metropolitan Area (Abreu e Silva and Goulias, 2009) to compare the results obtained.

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 kilometres (2003 OD survey). The 2003 OD survey allowed collecting data from 5% of the residing population (around 70,000 household and 170,000 people). These surveys collect attributes on households and people as well as all spatial-temporal features of the trips done by the 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 modelling experiences (Lisbon and Seattle), a subset of the total sample of workers (43,145) was randomly selected. Hence, some 7277 observations (workers) are used for the estimations.

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. Is 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. The following table 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 motorised households	19%	71%	87%	94%
Cars	5%	33%	51%	67%
Transit trip	13%	64%	84%	94%
Trips	7%	40%	58%	72%
Non-motorised 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 dispersion of population segments and features around the CBD:

- Higher concentration of 55 years and older, 1 person households, non motorised households and transit trips
- Higher dispersion of children and cars.
- 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 behaviour and socioeconomic characteristics

Variables		Average	Standard Deviation
Endogenous travel behaviour 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	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 between socioeconomic characteristics, land use patterns, relative residential and employment locations, car ownership and travel behaviour. The proposed model structure, 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 behaviour of employed individuals (workers);
- This influence is assumed to be at least partly mediated by variables describing several travel behaviour 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 behaviour variables, thus encompassing possible effects due to the fact that travel behaviour 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 the next figure. The overall structure used in the Lisbon and Seattle models is equal. 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.

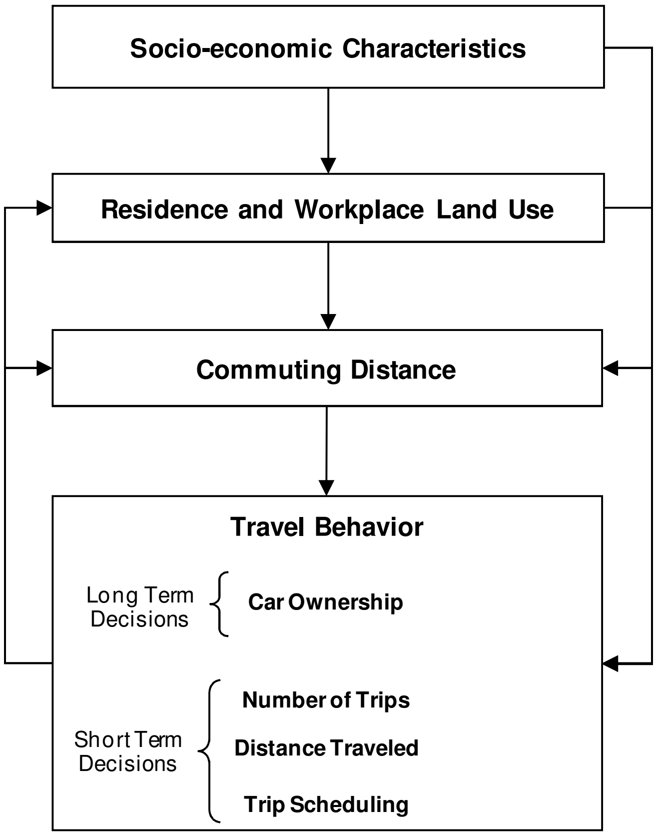

Figure 1 - Model general structure

The socioeconomic variables used in the model include: gender, age, household total 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 teenagers.

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, respectively labelled home and work.

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 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 a gravitational model), 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 kilometre 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 variation). The factors and their defining variables together with their scores are presented in the next table.

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 intensity, 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 choices and they are used as five dependent variables in a system that includes travel behaviour 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.

STRUCTURAL EQUATION MODELLING

SEM (Structural Equations Modelling) 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. Due to these characteristics Structural Equations Modelling is particularly adequate as a tool to model the complex relationships between travel behaviour and land use patterns.

A structural equation system with observed variables only (which could be also referred as path analysis or simultaneous equation modelling), as the one presented in this paper (no measurement sub models) can be expressed as:

$$y = \mathrm{B}y + \Gamma x + \zeta$$

Where:

y is the vector of *p* endogenous variables;

x is a vector of *q* exogenous variables;

$\boldsymbol{\zeta}$ is a vector of *p* disturbances with variance-covariance matrix $\boldsymbol{\Psi}$;

$\mathbf{B}$ is (*p* by *p*) matrix containing the coefficients for the equations relating the endogenous variables;

$\boldsymbol{\Gamma}$ is a (*p* by *q*) matrix containing the regression coefficients for the equations relating endogenous and exogenous variables.

The model-replicated combined variance-covariance matrix of the observed (p) endogenous and (q) exogenous variables, arranged so that the endogenous variables are first, is given by the partitioned (p+q by p+q) matrix (Kaplan, 2000; Golob, 2003a).

$$\sum(\theta) = \left[\begin{array}{c|c} (\mathrm{I}-\mathrm{B})^{-1}(\Gamma\Phi\Gamma' + \Psi)\left[(\mathrm{I}-\mathrm{B})^{-1}\right]' & (\mathrm{I}-\mathrm{B})^{-1}\Gamma\Phi \\ \hline \Phi\Gamma'\left[(\mathrm{I}-\mathrm{B})^{-1}\right] & \Phi \end{array}\right]$$

Estimation of SEM models is performed by using the covariance analysis method – method of moments (Golob, 2003).The objective function is to minimize the differences between the sample variance-covariance matrix, S, and the model-replicated matrix $\Sigma(\theta)$.

The methods used for model estimation are normal theory maximum likelihood – ML, generalized least squares – GLS and weighted least squares – WLS (Golob, 2003a, b).

WLS, the method used to estimate the model presented in this paper was specifically developed to deal with discrete and censored variables. Its genesis occurred with a multivariate probit developed by Muthen (1979). Later this method was generalized by Muthen (1984) to accommodate structural equations with a mix of discrete, censored and continuous variables (Golob and Reagan, 2002).

WLS minimizes the following fit function (Jöreskog and Sörbom, 2001):

$$F(\theta) = (s - \sigma)' W^{-1} (s - \sigma)$$

Where:

s' is the vector of the elements in the lower half, including the diagonal of the covariance matrix ***S***;

$\boldsymbol{\sigma'}$ is the vector of corresponding elements of $\boldsymbol{\Sigma(\theta)}$, reproduced from the model parameters $\boldsymbol{\theta}$; $\boldsymbol{W^{-1}}$ is the positive definite weight matrix of order u by u, where ***u=(P+q)(P+q+1)/2***. These weights are estimates of the fourth-order moments (the variances of the covariances).

The direct effects in the SEM model are given by the parameters of the $\boldsymbol{B}$ and $\boldsymbol{\Gamma}$ matrices and can be interpreted in the same way as regression coefficients (Kaplan, 2000). For an identified SEM model the total effects of the exogenous variables on the endogenous variables (the coefficients of the so-called reduced-form equations) are given by $\mathbf{(I - B)^{-1}\,\Gamma}$ and the total effects of the endogenous variables on one another are given by $\mathbf{(I - B)^{-1} - I}$ (Golob, 2003a), they are deducted from the general model expression solved in order to y (Kaplan, 2000). The indirect effects are given by the differences between the total and direct effects.

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 3 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)	Household Income	Household size	Household with teenagers	Adults average age	Number of workers	Household with 1 member	Household with 2 members
Nº trips - car	0.236 *7.760*					-0.137 *-11.983*			-0.020 *-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 *7.209*							
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), which is in accordance with the hypothesis that smaller households 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 its members tend to have higher car ownership levels also an hypothesis commonly accepted and presented in Lisbon and Seattle studies that used the same analytical method and model structure (Abreu e Silva et al, 2006, Abreu e Silva and Goulias, 2009).

The commuting distance is higher for men, also a commonly accepted result in the literature, and smaller for the smallest households (with only one member).

The model results show that land use variables are influenced by the socioeconomic variables, thus revealing and capturing the existence of self selection effects (i.e., different people reside in different places and both groups of variables influence travel behaviour).

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 that are also well served by roads.

Workers in households with teenagers and with a higher number of workers have a stronger probability of living in compact and small areas 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. Also 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 present 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 behaviour variables. Lack of significant explanatory variables may indicate an even spread of values across different sociodemographics.

The 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 *-33.680*	0.074 *15.377*	0.204 *27.021*		0.071 *12.156*	0.028 *4.989*	-0.021 *-3.747*	-0.024 *-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 hypotheses:

- Land use variables affect directly travel behaviour;
- Generally the relations between travel behaviour variables are consistent with the hypothesis that long term decisions condition shorter term ones;
- Land use variables are also directly influenced by travel behaviour 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. 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 presumably indicating the 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 hypothesis 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 behaviour 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.

The 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 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 hypothesis 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 behaviour 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 less cars tend to choose more central and denser locations.

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

Table 6 - Total 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	0.006	-0.093	0.010	0.047	-0.005	-0.032	-0.023	-0.013	0.004	-0.001	0.000	-0.003
	-4.636	*3.383*	*-4.641*	*4.518*	*4.435*	*-3.786*	*-4.635*	*-4.606*	*-4.466*	*3.977*	*-2.444*	*2.384*	*-3.956*
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	-0.005
		28.259	*-19.225*	*-16.583*	*10.840*	*7.781*	*-15.545*	*-16.480*	*-10.737*	*6.013*	*0.111*	*-3.740*	*-3.732*
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	0.022
		-5.237	*38.142*	*-17.651*	*-13.689*	*6.407*	*28.405*	*22.450*	*15.005*	*-7.867*	*2.869*	*-2.749*	*7.037*
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	-0.021
		-2.240	*2.277*	*17.025*	*-2.474*	*-15.132*	*4.744*	*16.412*	*-5.912*	*4.162*	*-0.746*	*2.508*	*-4.714*
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	-0.008
		5.738	*-34.999*	*-20.791*	*12.660*	*7.930*	*-23.914*	*-25.599*	*-12.697*	*6.197*	*0.111*	*-3.756*	*-3.772*
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	0.029
		-5.262	*5.737*	*-18.595*	*-13.939*	*6.514*	*45.180*	*25.781*	*16.456*	*-8.046*	*2.879*	*-2.762*	*7.133*
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	-0.024
		-2.260	*2.298*	*2.248*	*-2.508*	*-33.681*	*4.865*	*50.289*	*-6.200*	*4.138*	*-0.750*	*2.541*	*-4.887*
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	-0.052
		5.118	*-5.581*	*-4.933*	*5.819*	*7.037*	*-14.417*	*-14.392*	*-2.162*	*7.861*	*-1.469*	*-5.716*	*-6.439*
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	0.000
		3.977	*-4.190*	*-3.874*	*6.388*	*4.774*	*19.848*	*-40.352*	*6.402*	*15.339*	*12.561*	*-10.863*	*-4.506*
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	0.003
		-4.031	*4.248*	*3.933*	*-6.665*	*-4.820*	*6.031*	*5.746*	*2.062*	*-4.978*	*1.426*	*4.639*	*4.581*

Note: t-statistics in italic

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

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 feedback from the number of cars in the household and the number of car trips on commuting distance.

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

Also, living and/or working in central and denser areas increases the number of trips in transit or using non-motorized modes and at the same time decreases the number of trips by car. These effects propagate themselves to the number of kilometres 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, only living in small suburbs well served by roads increases the time spent outside home.

COMPARISON WITH THE LISBON AND SEATTLE MODELS AND CONCLUSIONS

One of the main objectives for building this model was to compare its results with two similar models built for the Lisbon Metropolitan Area (Abreu e Silva et al, 2006) and the Seattle metropolitan area (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 kilometres 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 were related with the number and breadth of land use variables which in the Lisbon and Montreal models were vaster than in Seattle.

In the Montreal and Lisbon models land use variables were mainly built at the zone level, whereas in Seattle a grid cell of 750x750 m, 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 (aka spatial choices) are influenced by travel behaviour variables which could be explained by the fact that travel behaviour is among other things the visible result of personal preferences and lifestyles and people chose bundles of choices.

But the main point might be that in all models land use variables affect travel behaviour in a significant way, thus giving weight to the argument of using land use measures as another available and effective policy tool to change travel behaviour.

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 and tailoring policies to residents with specific environment friendly lifestyles can be an effective action. Moreover, public transportation combined with land use can give us the desired outcome of lower car use.

The following general conclusions could be drawn from the total effects of all 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 car. 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.

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 kilometres travelled by car and increases the distances travelled by public transport. When looking at the total effects on the kilometres 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.

But from the differences present in these three models it is possible to drawn 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 an evidence of competition among modes, whereas in Seattle there is no such evidence. 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 and 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 factor (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, public transportation system is a more convenient option when compared with Seattle and, in a smaller degree, with Montreal. This fact points again to the importance of public transport supply levels together with land use patterns.

Regarding socioeconomic variables all models stress the impact that income has on travel behaviour. 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 an evidence of strong gentrification processes occurring in Montreal.

The main conclusions that could be drawn from the results of these three models is 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 behaviour and land use patterns as well as the hierarchical decisions between long and short term decisions. The second is the fact that these results are strong evidence in favour of using land use policies as tools for changing travel behaviour. 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 this 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 communalities 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. And this is a process more complex than current policy practice.

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