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A Spatial and Temporal Analysis of the Effects of Land Use Clusters on Activity Spaces in Three Québec Cities

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Abstract. Previous literature on transportation and land-use has focused on the effect of individual land-use variables such as population and employment density on traditional measures of transportation demand, such as VKT and mode-split. The following work uses activity spaces as a dependent variable for transportation demand and uses neighborhood clusters to capture the effect of land-use on this variable. This paper is an extension of previous research that concentrated on one city (Montreal) for one period of time. The present paper uses similar methods to compare three cities (Montreal, Quebec and Sherbrooke) over multiple years (from 1998 to 2008). It also controls, and tests for the possibility of residential location self-selection bias. The main findings are that: activity spaces are clearly linked to land-use (through neighborhood clusters), as well as overall city size; that activity spaces appear to be growing over time where employment centers are fixed; that the methodology used is generalizable to multiple cities; and finally that despite having controlled for the possibility of residential location self-selection, the hypothesis of exogeneity of activity space size with respect to neighborhood choice could not be rejected.

Keywords. Activity space, neighborhood type, clustering, travel demand, simultaneous equation model, self-selection, urban form, regional planning.

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1. Introduction

Scholars and planners alike have looked at the impact of various land use and accessibility measures, such as population density and land use mix, to investigate the links between travel behavior and where one lives or works. The relationships outlined through much of this research however have unfortunately been plagued with inconsistent and often weak results (Ewing and Cervero, 2010) (Bento, Cropper, Mobarak, & Vinha, 2005) (Boarnet & Sarmiento, 1998). This has led to a new generation of transportation and land use literature that investigates clusters of land use indicators, which in turn has resulted in more consistent and stronger relationships between land-use and travel behavior (Manaugh et al., 2010) (Lin & Long, 2008) (Shay & Khattak, 2007).

The dependent variables investigated have also most often been related to traditional travel demand outcomes such as vehicle kilometers traveled (VKT) or mode share. More recently, a growing desire to understand the non-work travel behavior of individuals and households has spawned interest in yet another dimension of mobility; activity spaces (Buliung and Kanaroglou, 2006).

Outcomes like vehicle kilometers traveled or mode share were aimed, first and foremost, at understanding peak demand for road space or transit seats. Where the use of activity spaces as a travel behavior indicator differs from such an approach is that it seeks to represent and understand the spaces where households interact with their cities, and do so to better understand the total travel demand, as opposed to its peak (Fan & Khattak, 2008). Activity spaces allow researchers to look at the spread or distribution of activities throughout space.

Combining a clustered approach to defining neighborhood typologies, as described in Miranda-Moreno et al. (2010), with an analysis of household activity spaces in the Montreal, Quebec and Sherbrooke census metropolitan areas (analogous to US MSAs), this paper investigates the influence of environmental factors on household activity spaces. Building upon previous work conducted using a subset of the land use variables and data for the Montreal region alone (Harding, Patterson, Miranda-Moreno, & Zahabi, in press), traditional measures such as population and employment densities, land use mix and public transit accessibility are clustered to create a neighborhood typology for each of the cities. Activity space polygons are then generated from two distinct origin-destination surveys for Quebec, three for Montreal, and one for Sherbrooke. By creating typologies and linking households to them, one can establish links between the type of environment inhabited and the ways in which we move about. This allows us to gain a better understanding of which combinations of land use and transportation factors enable households to most efficiently satisfy their needs for accessibility, while curbing the ever-expanding growth in mobility.

Analysis of the interaction between neighborhood types and activity spaces will focus on properties of the spaces such as area and compactness. Outputs will be analyzed using ordinary least squares regression, but also simultaneous equation modeling (SEM) to account for potential joint residential location-and-vehicle ownership choice. This is done to account for residential self-selection biases, and results from these two approaches will be compared to test for variable endogeneity. In this evaluation of the statistical influence of land-use on activity spaces across three cities and multiple years, census and household level socio-demographic variables will also be used to control for factors unrelated to neighborhood type.

The large sample size of the origin destination (OD) surveys (nearly 250,000 households when pooled together) combined with the element of evolution through time and over multiple landscapes provides new information to the field, notably with respect to discussion of efficient city size.

As the results will illustrate, differences between cities, as opposed to differences within them, seem to be the largest factor influencing the spread of activities throughout space; a finding while perhaps intuitive, appears to be downplayed in the literature on transportation and land use linkages.

2. Literature Review

The following section will provide a brief description of the issues dealt with in this paper, with a particular emphasis on activity spaces and their various interpretations.

2.1 Urban form and its effect on travel behavior

The transportation sector in Canada accounts for 26% of our GHG emissions (Environment Canada, 2007). With a growing concern over the effects of suburbanization on citizen health and that of our environment and economy, reassessing our de-facto development patterns becomes imperative. The three (or five) Ds are the traditional means by which urban form is quantified and classified; notably density, diversity and design as the former, and destination accessibility and distance to transit as the latter (Krizek, 2003) (Transportation Research Board and Board on Energy and Environmental Systems, 2009). Work that looks at these variables with respect to travel demand usually links increases in density, diversity and destination accessibility to lower vehicle kilometers traveled, while improvements in the design of neighborhoods and reduction in the distance to transit are often related to higher active and transit mode shares (Ewing & Cervero, 2001) (Ewing & Cervero, 2010). Essentially, ever since academics began looking at the effect of the built form on travel demand, "employing land-use policy as a tool to reduce vehicle travel" has been a popular undertaking" (Bagley, Mokhtarian, & Kitamura, 2002). Such a view of the city and its dynamics is not without its critics however, who look upon the projected reductions in VKT or GHG emissions from increased levels of urban density or better transit accessibility with a critical eye. Boarnet & Sarmiento (1998) for example draw attention to the issue of residential self-selection and warn against taking reported elasticities at face value where this issue is not taken into consideration.

2.2 Clustering for clarity

Approaches to measuring the effect of urban form variables on travel demand without encountering the problems that arise when using individual variables include the use of principal component analysis to create indices of urbanity (Bagley, Mokhtarian, & Kitamura, 2002), or the clustering of variables together to create neighborhood types (Shay & Khattak, 2007) (Riva, Apparicio, Gauvin, & Brodeur, 2008) (Gershoff, Pederson, & Aber, 2009) (Bento, Cropper, Mobarak, & Vinha, 2005). Whereas traditional research focusing on individual indicators ignores the interactions that exist between different descriptors, clusters, or neighborhood types, group together observations based on similar combinations of indicator levels.

Local planning agencies can use information about responses to neighborhood type in a holistic way, to both improve the lives of residents, and also maximize the utility of infrastructure expenditure.

2.3 Residential Self-Selection

Another issue with relating urban form to travel behavior is that of self-selection. At its simplest, self-selection occurs when “households or individuals who have a proclivity towards a certain lifestyle may choose or “self-select” to reside in neighborhoods that support their lifestyle preferences” (Eluru, Bhat, Pendyala, & Konduri, 2010, p. 604). Thus, inferring from travel behavior that people residing in certain types of environments move about in a given way because of their exposure to that environment, as opposed to seeing their behavior as something innate may be erroneous (Leck, 2006). Some studies have pointed towards important residential self-selection effects, such as Currie, et al. (2010), who found that "almost half of those without a car rated 'close to public transport' as the most important factor" in their residential location choice (p.290).

2.4 Interpreting activity spaces

When measuring activity spaces of people or households, what we obtain is an assessment of spread or dispersion. This analysis can be performed using a variety of GIS tools and geometries, such as road network buffers (RNB), minimum convex polygons (MCP), standard deviational ellipses (SDE), etc. For an overview of these different measures and their applications, see (Buliung & Kanaroglou, 2006) and (Rai, Balmer, Rieser, Vaze, Schonfelder, & Axhausen, 2007).

As Newsome, Walcott, & Smith (1998) explain, "the observed activity space may or may not represent the maximal area over which the traveller could engage in activities, but rather the area over which they are likely to regularly engage in those activities" (p. 361). "It is widely agreed by psychologists and geographers that traveling through an environment is the most common way of spatial learning and acquiring spatial expertise" (Schonfelder & Axhausen, 2003, p. 279). This spatial expertise, or the addition of details to a given person's mental map, is what shapes future travel patterns. A similar argument could be made that our social networks, like our physical exposure to the world around us, add to our awareness space, leading to further travel. This is one of the reasons why measuring the influence of information and communications technologies (ICTs) on activity space has been carried out in one form or another - as a means by which to evaluate the effect of the increasing number of weak ties in our social networks (Axhausen, 2007).

Another motivation for the study of activity spaces is that as the proportion of work trips, and by association peak-hour trips, decreases over time (Axhausen, 2007) (Black, 2001), understanding the whole picture of travel demand becomes more and more important; whether it be to assess safety of roads at off-peak periods, gain a better understanding of GHG emissions or social exclusion.

"The geometry, size and inherent structure of activity spaces are … determined by three important determinants: [Home, regular activities and the travel between and around the pegs]" (Schonfelder & Axhausen, 2003, p. 275). The idea in much of the work on activity spaces to date is then to understand and link the properties of the poles to specific types of travel behavior, enabling forecasts of the travel demand resultant from changes to the urban form.

On the question of whether smaller activity spaces represent a good or bad thing, the current literature lacks consensus. Some researchers have investigated whether small spaces per se indicate transportation disadvantage, but the results to date have been inconclusive (Schonfelder & Axhausen, 2003). More often than not, the conclusion is that very detailed demographics are needed to properly interpret size or compactness of the space. Some low-income and high car ownership households in Currie et al.'s paper, for instance, spent up to 50% of their income on transportation. Such an outcome is a prime example of what we should seek to avoid by better coordinating the development and attribution of housing, services and amenities, and employment in a way that people are empowered to choose where to live, and not restricted in their options to locations where car ownership is a prerequisite to participation in the community.

3. Study areas & data used

In order to test the effect of clustered land use variables on activity spaces, both across time and in cities of different size and structure, we chose to go with the largest cities in Quebec for which comparable data was available. Montreal, Quebec and Sherbrooke all have comprehensive OD surveys, and they are respectively the 1st, 2nd and 4th largest census metropolitan areas (CMAs) in the province – the third being Ottawa/Gatineau, a CMA that was precluded from analysis because it crosses the Ontario/Quebec border. In addition to OD surveys (Montreal and Quebec having them carried out every 5 years), the selected CMAs share comparable employment and demographic, and land use and urban form data. They also differ greatly with respect to their development patterns, transportation infrastructure and overall populations.

Montreal is the cultural and economic hub of the province, with over half its population, while Quebec is the province's political and historic capital, with a more sprawled urban form than that of Montreal, lower overall densities and transit offering, and a less diverse population. Sherbrooke, the only city in the sample not along the St-Lawrence seaway, used to be an industrial town, but is now home to the largest concentration of university students in the province. In 2006, their respective populations were 3,635,571 (Montreal), 715,515 (Quebec) and 186,952 (Sherbrooke) (Statistics Canada, 2006).

OD Data

The main sources of data in each city are their OD surveys. Each survey contains data on all the trips taken by every person 4 years and older in the household, on the day prior to the survey. These surveys contain information on 5 to 10 percent of the households in each region.

UF and BE variables

To enable the creation of neighborhood types, it is necessary to have indicators to cluster. The main sources of spatial data used in the creation of indicators are land use data obtained from DMTI Spatial, census tract boundaries for each CMA, and census socio-demographics obtained from Statistics Canada.

To characterize public transit accessibility, data was obtained from a variety of sources. The network for Montreal was built up as a hybrid network, composed of a base originally geocoded in TransCAD by

Dr. Murtaza Haider of Ryerson University in 2003, upon which were added additional lines to cover the extent of the CMA. The development of this base network was supported by a grant from the National Sciences and Engineering Research Council (NSERC) as well as infrastructure provided by the Canada Foundation for Innovation (CFI). Off-island transit lines were subsequently added in the summer of 2011. Both parts of the network were geocoded by hand since network information (property of five main transit operators) is not generally available outside of those institutions.

For Quebec, the Réseau de Transport de la Capitale supplied us with bus line stops and headways, while the Société de Transport de Lévis provided lines, from which stops were generated and headways approximated.

As for Sherbrooke, the Société de Transport de Sherbrooke supplied us with GTFS data (General Transit Feed Specification), as well as tables containing additional service which is run when the university and CEGEP semesters are in session.

Differences in data sources do lead to values not directly comparable across cities, but given that standardized values are used in cluster analysis, and that cities are all run in separate models, the differences in measurement accuracy did not prove problematic.

4. Methodology

The methodology employed to generate the clusters is similar to that which is outlined in (Harding, Patterson, Miranda-Moreno, & Zahabi, in press) and (Miranda-Moreno, Bettex, Zahabi, & Kreider, 2011).

4.1. Indicator Generation

4.1.1. Densities

To calculate densities, we obtained population and employment counts per census tract for each of the census years nearest our OD surveys (1996, 2001 and 2006). We then assigned population figures obtained from Statistics Canada to the portion of tracts occupied by residential land uses and jobs to commercial, industrial and institutional land uses, enabling us to calculate net densities.

To better understand the distribution within tracts, we intersected the land-use isolated tracts with a 500 meter grid. This enables generation of cell-level population and employment densities. Weights were applied to control for incomplete cells near bodies of water or at the border of the study region and cell densities were averaged out with those of surrounding contiguous cells to avoid peaks.

4.1.2. Land use mix

Land use mix was also captured and averaged out at the grid cell level. Using DMTI Spatial's land use data, we calculated cell occupancy for each type of land use, then applied an entropy formula (see below) to calculate relative mix.

$$E_j = -\sum_{i=1}^{n} \frac{\left[\left(\frac{A_{ij}}{D_j}\right) ln\left(\frac{A_{ij}}{D_j}\right)\right]}{\ln(n)} \qquad \text{Eqn. (1)}$$

Where:

E_j : land use mix of cell j (from 0 = no mix, to 1 = perfect mix)

A_{ij} : area occupied by land use i in cell j

D_j : area of cell j (excluding water and open area)

n : total number of different land uses

4.1.3. Public transit accessibility

To calculate transit accessibility, headways and distances between stops and cell centroids were used. Since there is theoretically no limit to how many transit lines can be near a cell centroid, the resulting value is unbounded. The following formula was applied:

$$PTaccess_j = \sum_{i=1}^{n} \frac{1}{(d_{ij} * h_i)} \qquad \text{Eqn. (2)}$$

Where:

$PTaccess_j$: accessibility to public transit at cell j

d_{ij} : distance, in km, from cell centroid j to nearest bus stop of line i (minimum value of 0.1 km)

h_i : average headway, in hours, of line i (in AM peak with a maximum value of 1 hour for Montreal and all-day with a maximum value of 2 hours for Quebec and Sherbrooke)

In general, the transit offering in Montreal can be understood to be considerably greater than that of either Quebec or Sherbrooke. Montreal has an underground subway system offering frequent service connecting most central locations, as well as a good feeder bus network operating outside of this, express buses and commuter rail for residents further away from the core. Sherbrooke and Quebec offer bus and minibus service, but not at a comparable level to Montreal.

4.2. Neighborhood typologies, or clusters

Once the indicator values were compiled, k-means cluster analysis was used to generate the typology for each city. To ensure that grid cells would be associated to the same cluster for the duration of the years of analysis, only the last year's cell level indicator values were used in clustering. Also, as magnitudes affect clustering behavior (Song & Knaap), indicators were standardized beforehand.

To ensure a more objective choice for k (number of clusters), Calinski-Harabasz values were generated for each k between 2 and 8, and for each city. The highest value obtained indicating the optimal number of clusters, or that which maximizes the between-cluster sum of squares while minimizing both the within-cluster sum of squares and number of clusters (Dimitriadou, Dolnicar, & Weingessel, 2002). This approach, combined with a visual evaluation of the clustering, resulted in the choice of 5 clusters for Montreal, 4 for Quebec and 2 for Sherbrooke.

4.3. Activity spaces

Since we had access to single day trip information for households through the OD surveys, the minimum convex polygon (MCP) was chosen. Unlike the standard deviation ellipse (SDE) or standard deviation circle (SDC), the MCP does not have the tendency to exaggerate the space occupied by households when observations are low - something we sought to avoid. The MCP simply forms the smallest possible convex polygon around the locations visited by a person or household (see Figure 1).

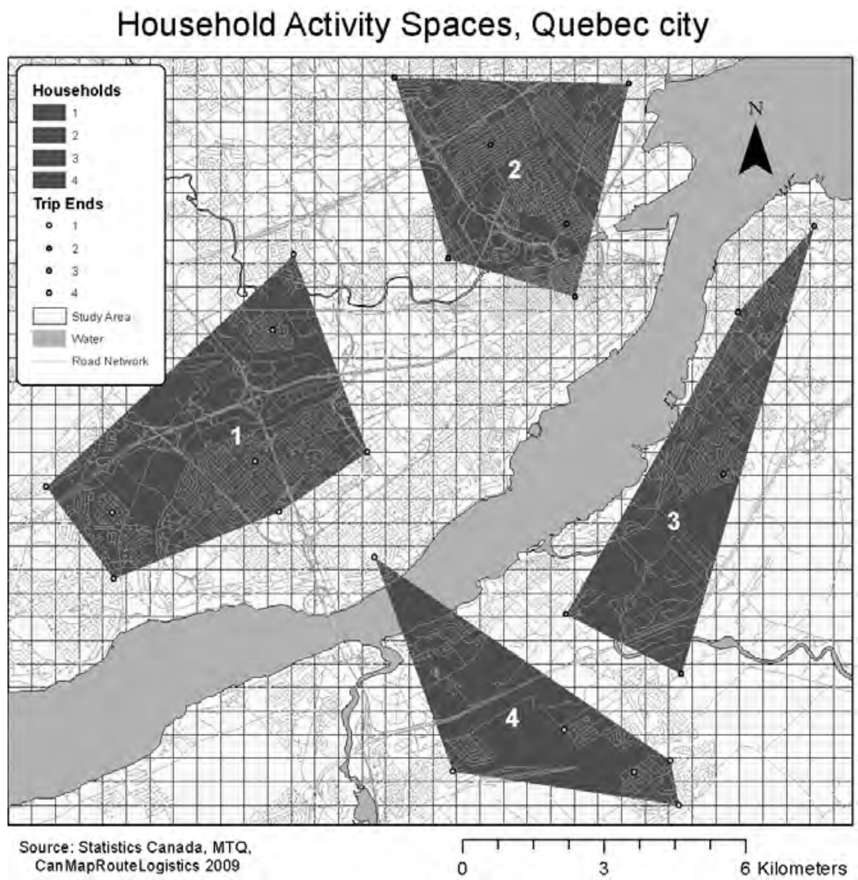

Figure 1: Activity Space generation, synthetic example set in Quebec

Classification of trip purposes varies from study to study (Newsome, Walcott, & Smith, 1998) (Manaugh & El-Geneidy, 2012), but generally accepted mandatory trips are those made for work or school, while non-mandatory trips are those carried out for shopping and leisure, or to meet friends and acquaintances. To get a better idea of typical total household travel, as opposed to simple AB-BA commutes, we isolated households that made both types.

Another issue that we have little control over with one-day surveys is that only certain activities will be accounted for with respect to households' habitual travel (Schonfelder & Axhausen, 2003). It is our contention however, that the sheer number of OD observations we have to work with circumvents this issue of non-representative results, as one can imagine that the trips undertaken when mandatory and non-mandatory activities are required to form a polygon are at the very least indicative of the propensity for a household to either spread about or concentrate their activities.

4.4. Analysis

Much the same way that continuous built environment variables, like persons per hectare or street-grid connectivity, are used to predict VKT, we used the neighborhood types generated above to estimate built environment effects on activity space size. The following section describes the techniques employed to do so.

In order to make inferences about neighborhood effects, we must control for demographic differences in each neighborhood's households. In addition, the approach employed controls for this self-selection by modeling the choice of owning a vehicle and choosing to live in a certain type of environment simultaneously. This technique and its theoretical foundations are described in (Miranda-Moreno, Bettex, Zahabi, & Kreider, 2011). We treated residential location and vehicle ownership as a joint choice, influenced by a series of endogenous household variables. This was done in addition to running an OLS model with the same potentially endogenous variables, alongside a cluster-car ownership logit model. With the results of both, we were able to test the hypothesis of exogeneity in our treatment variables. This was done by comparing the Akaike Information Criterion (AIC) value produced by the SEM, with that of the OLS added to that of a multinomial logit (MNL) model, whose dependent variable was the cluster-car joint choices and independent variables the treatment variables. Lower AIC values suggest better fit (Congdon, 2003).

$$\ln(ActSp_i) = \beta x_i + \sum_{j=1}^{n} \mu KC_{ij} + \sum_{j=1}^{n} \lambda_j l_{ij} + \epsilon_i$$

$$U_{ij} = \beta_j x_i + \delta_j l_{ij} + \eta_{ij} \qquad j = 1, \dots, n$$

where:

$ln(ActSp_i)$ = Area of activity space for household i;

x_i = socioeconomic characteristics of household i;

KC_{ij} = dummy variables representing neighborhood and vehicle ownership cluster j for household i;

ϵ_i = random independent error of activity space (normal distribution);

U_{ij} = utility of choice of KCj for household i, where

j = 1, . . . , n;

l_{ij} = latent explanatory variable of heterogeneity not observed by endogenous variables;

β_{ij} = random independent error of vehicle ownership (normal distribution);

and

β, δ, λ, and μ = model parameters.

The SEM was run using the mtreatreg plugin in STATA developed by Deb and Seck (2009).

We also chose to treat household composition as a series of binary variables as opposed to continuous variables. Results were thought to increase legibility for groups like families with children and singles for example, where one would suspect an intuitive preference for suburban or urban living. This echoes the methods used by Eluru et al. (2010).

5. Results and discussion

The following section will present the main findings of our research. We will begin by presenting the typology for each city, accompanied by summary statistics for the most relevant variables, followed by results of the OLS regression presented side by side with those of the SEM described above.

5.1. Summary Statistics

Neighborhood Type	Activity Space (km2)	Household Count	Persons per Household	Unique Locations	Cars per Household	% Families with Children	Pop Density (per Hectare)	Job Density (per Hectare)	Land Use Mix	Public Transit Access
Rural	83.66	15,147	3.32	4.70	1.96	59%	13	2	0.08	9
Suburban	54.49	25,596	3.16	4.70	1.73	50%	27	8	0.30	38
Urban/ Suburban	27.09	13,700	2.94	4.47	1.31	42%	55	17	0.43	165
Urban/ Suburban	18.70	13,505	2.62	4.31	0.95	33%	96	44	0.53	286
Core	9.47	808	2.02	4.02	0.63	16%	75	314	0.62	516
Total/ Average	47.90	68,756	3.03	4.57	1.53	47%	44	19	0.32	111

Table 1: Summary statistics, Montreal

In Table 1, we see a few expected trends, such as smaller household sizes, less families with children and fewer cars per household in urban areas. The average activity space also decreases sharply as we move along the spectrum from rural to urban. This decrease in activity space also outpaces the decrease in both household size and vehicle ownership. With respect to urban form variables, the trend points to an increase in density, land use mix and public transit access as we move from the more rural to the more urban clusters, but we can also observe that population density does not increase in a linear way. This highlights why clustering is ideal when looking at urban form effects on travel demand, as it captures non-linear effects.

Finally, with respect to compactness - which can be described as the ratio between the perimeter of a circle of area X and the perimeter of a MCP having the same area-, there was no cluster level bias. As such, the values will not be reported, but the potential for such bias was investigated.

Neighborhood Type	Activity Space (km2)	Household Count	Persons per Household	Unique Locations	Cars per Household	% Families with Children	Pop Density (per Hectare)	Job Density (per Hectare)	Land Use Mix	Public Transit Access
Rural	42.12	10,664	3.19	5.14	1.84	55%	14	2	0.06	20
Suburban	26.64	8,548	2.99	5.04	1.63	44%	23	8	0.16	54
Urban	13.67	4,178	2.60	4.70	1.23	32%	44	27	0.26	114
Core	10.42	1,641	2.23	4.53	0.90	21%	72	86	0.30	276
Total/Average	30.01	25,031	2.96	4.99	1.60	45%	26	14	0.14	64

Table 2: Summary statistics, Quebec

With respect to Quebec city, similar trends to those for Montreal appear. Increases in urban-ness (higher cluster values) are associated with smaller activity space polygons, while densities and land use mix increase as we approach the core. Interesting to note first and foremost is the large difference in average activity space size between our two cities. Whereas Montreal has an average activity space of around 48 km^2, Quebec City residents produce an average activity space polygon of around 30 km^2, 37.5% smaller. This is an interesting finding in many respects, notably because Quebec has a lower population density and more unique locations visited per household, despite smaller household sizes and lower land use mix. It would seem therefore that the absolute size of the census metropolitan area has a significant impact on the travel behavior of residents, one even greater than neighborhood attributes.

Neighborhood Type	Activity Space (km2)	Household Count	Persons per Household	Unique Locations	Cars per Household	% Families with Children	Pop Density (per Hectare)	Job Density (per Hectare)	Land Use Mix	Public Transit Access
Suburban Carless	3.08	40	2.30	3.78	0.00	10%	16	4	0.15	45
Suburban W-Car	20.97	1,515	3.09	4.91	1.79	38%	11	3	0.10	36
Urban Carless	2.92	148	1.91	3.90	0.00	5%	26	16	0.37	149
Urban W-Car	9.90	1,082	2.66	4.69	1.48	23%	24	15	0.37	128
Total	15.45	2,785	2.85	4.75	1.55	30%	17	8	0.22	78

Table 3: Summary statistics, Sherbrooke

Sherbrooke being a much smaller CMA than Montreal or Quebec, it was interesting to bring it in to the analysis. As a result of their only being 2 clusters for the region and of the low number of observations for households with no car in general, it seemed interesting to present the table of summary statistics broken into cluster-car combinations (as they are used in the regression models that follow).

Sherbrooke shows similar intra-city patterns with regards to the relationship between activity space size and neighborhood types, but also further validates the finding relative to absolute city size. Sherbrooke represents a significant overall decrease in activity space when compared to the larger CMAs: the average activity space of a household living in Sherbrooke is just over half that of households in Quebec City. As was the case when comparing Quebec to Montreal, this precipitous drop in activity space occurs despite a decrease in the density of population and employment. The land use mix is however higher in Sherbrooke than Quebec.

Regarding which factors might explain the stark differences in activity space size between cities, the effect of public transit network coverage and service offering was considered. Montreal's metro and commuter rail systems carry transit riders over longer distances than Quebec or Sherbrooke's bus networks, but given that mode share for transit is considerably lower than for automobiles, this would be a simplistic conclusion. The main difference rather, would seem to be that irrespective of how some employment is suburbanizing, all three CMAs still function as coherent wholes; commuting patterns being at the heart of their definition. As such, if most or all of the specialized employment is found at the core, and if this core keeps getting further and further from where people live (on average, as the CMA increases in size), then it is inevitable that people will travel greater distances to access these resources.

5.2. Linear Regression and Simultaneous Equation Model

To further investigate the trends in travel dispersal within and between cities, OLS and SEM models were employed. The dependent variable in each model is the logarithm of the activity space.

To begin, using the AIC test for endogeneity of variables, explained in section 4.4, the hypothesis of endogeneity is rejected. The sum of the OLS AIC and the MNL AIC, using the same explanatory variables as treatments in the SEM, was inferior to the AIC value of the SEM alone. The detailed results that follow do however exhibit certain interesting changes to coefficient values between the OLS and the SEM. These changes would tend to indicate that some travel behavior or some location-and-vehicle ownership choice may be due in part to specific predispositions of members of certain types of households. Exogeneity as a whole, or the validity of the OLS approach, cannot however be rejected.

		OLS		SEM	
	Variable	Coeff.	t-stat	Coeff.	t-stat
NO CAR	RURAL	-0.99	-6.67	-0.73	-4.57
	SUBURB	-1.23	-20.17	-1.36	-16.50
	URB/SUB	-1.15	-25.74	-1.18	-19.97
	URBAN	-1.52	-42.19	-1.58	-32.11
	CORE	-2.55	-29.36	-2.48	-24.66
CAR	RURAL	OMITTED		OMITTED	
	SUBURB	-0.36	-19.71	-0.38	-7.07
	URB/SUB	-0.74	-31.23	-0.76	-9.71
	URBAN	-1.02	-38.09	-1.08	-19.64
	CORE	-1.78	-20.97	-1.72	-18.75
	Laval	0.15	7.59	0.15	7.59
	Unique Locations	0.50	104.96	0.50	104.98
	FT Workers	0.27	28.15	0.27	28.00
	Students	-0.05	-5.43	-0.05	-5.43
	Licenses	0.20	19.40	0.19	16.22
	FG Empl.	-1.76	-10.81	-1.75	-10.80
	Homemakers	2.22	17.25	2.22	17.28
	Single Female	-0.10	-2.64	-0.10	-2.66
	Single Male	0.11	3.00	0.11	2.89
	Couple	0.09	3.83	0.09	3.71
	SS Couple	0.19	5.55	0.19	5.61
	Single Parent	-0.30	-9.48	-0.30	-9.35
	Family with Kids	-0.14	-6.10	-0.14	-6.18
	2003	0.09	5.80	0.09	5.81
	2008	0.12	8.00	0.12	8.01
	Constant	13.92	198.02	13.96	182.50

Number of obs.		68,756		
R-squared		0.34		
Adj R-squared		0.34		
AIC		261,785	AIC	469,284
(AIC mlogit)		207,318		

Table 4: Regression results, Montreal

All the variable coefficients in the Montreal regression shown in Table 4, are right-sided and significant. The omitted category is “Rural With Car” and all the other cluster-car binary variable coefficients make sense interpreted in relation to this (all other neighborhood types are estimated to produce smaller activity spaces ceteris paribus). In addition, there is only one case for which the progression from Rural to Core does not decrease the value of the coefficient (which would indicate activity spaces are getting smaller as cluster cells become more urban), and that is clusters Suburban and Urban/Suburban. The demographic characteristics of the households found in the intermediate Urban/Suburban cells may explain the reversal, or it may be the case that this cluster happens to be found often-times near commuter rail stations, which although considered public transit, by definition carry individuals over long distances, leading to large activity spaces. This cluster has a very high level of public transit access overall for example – leaps and bounds above the Suburban cluster. These households may also be more active than normal suburbanites, as demonstrated by the lower number of persons per household, yet the same number of unique locations visited as rural households. Overall the cluster-car portion of the model seems to work well.

The rest of the variables’ coefficients are also intuitive, with Laval (an island and important suburb just North of Montreal), number of unique locations, full time workers and licences all increasing the activity space size.

As was the case in Harding et al., a census tract variable that was found to be significant with respect to predicting decreases in activity space size was FG (or employment in sales, services and the arts). From an econometric perspective, “location choices are determined by the extent of spatial variation in wage rates and in housing price” (Madden, 1981, p. 183), meaning that households with lower wage elasticities for the industries in which they work will be expected to live closer to their job, or to choose their job more as a function of where they live. Employment in sales and services fit this description.

Homemakers, another census tract variable that represents the percent of women at home that perform 15 hours or more of unpaid child care was positive and significant. Many of the tracts with high percentages of women performing multiple hours of unpaid child care are wealthy tracts some distance from employment centers. Many residents of these tracts likely work in specialized fields garnering large enough incomes to justify both a long commute (to reach a job in a specialized employment cluster) and a high tract income despite many stay at home mothers.

Single parents also came out as a significant variable that reduced the average activity space size. This is consistent with the literature on the effect of children on the time budget of single parents, a disproportionate share of whom are also women (MacDonald, 1999). Families with children produced a similar, albeit smaller, coefficient. Couple and SS Couple coefficients (two adults living together with no children, whether they are of the same sex or not) complement this finding, with positive values.

The last noteworthy trend is the positive and increasing coefficient for the 2003 and 2008 binary variables. This finding would concord with the hypothesis that as households gain more time for leisure and more access to ICTs their social networks would increasingly be disconnected from the location in which they reside, resulting in larger activity spaces through less dense and more dispersed travel behavior (Axhausen, 2007).

	Variable	OLS Coeff.	OLS t-stat	SEM Coeff.	SEM t-stat
NO CAR	RURAL	-0.73	-4.49	-0.87	-3.94
	SUBURB	-1.11	-11.85	-1.30	-9.67
	URB/SUB	-1.55	-23.40	-1.74	-15.42
	URBAN	-2.10	-28.60	-2.25	-23.11
CAR	RURAL	OMITTED		OMITTED	
	SUBURB	-0.28	-11.69	-0.30	-2.03
	URB/SUB	-0.77	-20.91	-0.90	-9.48
	URBAN	-1.09	-20.48	-1.17	-12.74
	Unique Locations	0.39	70.47	0.39	70.48
	Thurs/Fri	0.05	3.01	0.05	3.01
	Lévis	0.18	6.28	0.18	6.28
	Outer	0.18	6.85	0.18	6.84
	FT Workers	0.22	15.01	0.21	14.20
	Licenses	0.16	11.15	0.14	9.34
	Children	-0.12	-9.27	-0.13	-9.71
	FG Empl.	-0.42	-2.13	-0.42	-2.15
	Homemakers	2.64	14.94	2.64	14.97
	Family with Kids	0.08	2.88	0.07	2.50
	Couple2	0.14	5.62	0.13	5.26
	Single Parent	-0.13	-2.58	-0.14	-2.74
	2001	0.02	1.32	0.02	1.35
	Constant	13.44	179.94	13.54	143.75

Number of obs.		25,031		
R-squared		0.40		
Adj R-squared		0.40		
AIC		87,595	AIC	151,658
(AIC mlogit)		63,960		

Table 5: Regression results, Quebec

With respect to Quebec, the hypothesis of exogeneity is likewise not rejected (using the AIC values as a test), indicating that the OLS cannot be rejected as a valid means by which to model the influence of UF and BE variables on activity space generation. In this case, the influence of clusters actually increases when the SEM is run, which would indicate that the OLS, if anything, is underreporting the influence of neighborhood type.

The trend in coefficients going from rural to urban clusters in Quebec is the straightforward decrease we would expect (indicating that increases in urban-ness lead to smaller activity spaces). Once again, all the variables in the model are significant and right-sided.

The binary variable “Thursday / Friday”, indicating days where shops and service locations are open late, was found to have a statistically significant impact on activity spaces, causing an increase in their size. This is a variable not taken into account in traditional aggregate results, but echoes work on temporally constrained access to services (Neutens, Delafontaine, Scott, & De Maeyer, 2010), where store opening hours were found to make a significant difference in the travel patterns of individuals and households. Lévis and Outer, two variables that represent tracts further away, or separated by a bridge, from the historic core of the city also have significant and positive effects, as do licenses and number of full time workers.

The influence of Families with Children in this case is positive, but given that number of children is also included as an explanatory variable, this would seem merely to dampen the negative effect of children with respect to activity space size (more children decreasing the activity space, but not in a linear way). And finally, 2001 was included and left in the model despite not being significant to indicate the potential influence of time (the omitted category is 2006). Its effect is weak, but would appear to indicate a slight decrease in activity space size over time. From previous work on the region, it is our hypothesis that suburbanization of employment may be the cause of this weak and negative trend over time. Additional data would be required to confirm this.

	Variable	OLS Coeff.	OLS t-stat	SEM Coeff.	SEM t-stat
NO CAR	SUBURB	-0.95	-3.74	-0.69	-2.22
NO CAR	URBAN	-0.87	-5.43	-0.78	-3.75
CAR	SUBURB	OMITTED		OMITTED	
CAR	URBAN	-0.51	-6.90	-0.96	-4.31
	Unique Locations	0.41	25.34	0.41	25.36
	FT Workers	0.24	5.09	0.23	4.82
	Only Students	-0.48	-3.98	-0.44	-3.49
	65 plus	-0.32	-2.62	-0.29	-2.35
	Single Parent	-0.57	-4.80	-0.64	-5.21
	Family with Kids	-0.17	-2.53	-0.21	-3.00
	Homemakers	3.78	6.63	3.79	6.65
	Cars per Adult	0.33	3.58	0.32	3.57
	Constant	12.61	69.94	12.79	63.02

Number of obs.		2,785		
R-squared		0.34		
Adj R-squared		0.34		
AIC		10,092	AIC	14,793
(AIC mlogit)		4,691		

Table 6: Regression results, Sherbrooke

Finally, when looking at Sherbrooke (for which the hypothesis of exogeneity of explanatory variables is once again not rejected), we see that clusters are statistically significant predictors of activity space size. What is interesting however are the coefficients for carless clusters: in the OLS, the suburban households are predicted to produce smaller activity spaces than their urban counterparts (which would appear to be counter-intuitive), while in the SEM, the estimated relationship between urban-ness and activity spaces is reversed. As for clusters with cars, in the OLS, the coefficient for urban-with-car was smaller in magnitude than those for the carless clusters (as we would expect, since carless households in Montreal and Quebec have smaller activity spaces than their car-owning counterparts), but in the SEM, the coefficient for urban car-owning households is larger than those for non-car-owning households of either cluster. This interesting set of reversals may result from the fact that so few observations exists for car-less households in the sample (see Table 3), combined with the fact that the study region as a whole is so much smaller than that of Quebec or Montreal.

The above would tend to indicate that the effect of neighborhood type, albeit significant in larger cities, is lessened when looked at in smaller cities. This finding further emphasizes the need to properly evaluate policy regarding the use of urban planning as a tool for achieving sustainable outcomes, so as to account for city size as a whole, not merely neighborhood design. It is important to note that suburban, car-owning households in either model are predicted to produce activity spaces significantly larger than any other cluster.

For the rest of the coefficients, we can observe intuitive right-sided and significant relationships. Each unique location visited, as well as each additional full time worker and car per adult adding to the activity space, while persons over the age of 65, households comprised only of students (included because of the large student population in Sherbrooke) and single parent households decrease the activity space.

5.3. Self-Selection bias and endogenous variables

As mentioned in section 4.4, a mixed multinomial logit model was built using household composition types and additional household variables to evaluate the effect of a possible joint-choice in cluster and vehicle-ownership. Unlike Miranda-Moreno et al., who used a similar cluster-car and SEM approach, but to predict vehicle kilometers traveled, our model did not reject the hypothesis of exogeneity in variables. One reason this may be the case is the availability of different types of neighborhoods in each city, making it possible for households to make residential location choices that do not lead to forced car ownership or spatial mismatch.

6. Conclusion

Our results indicate that both local and regional descriptors of the built environment, neighborhood types and city size, can be used to predict the dispersal of travel through space. Neighborhood types are found to have a statistically significant effect on these spaces, even after accounting for household composition, vehicle ownership and census tract properties. Results, overall, signal that efforts at affecting changes to the travel behavior of households through the use of urban planning at both the local and regional scale are valid pathways to be explored.

With respect to temporal effects, results for Montreal seem to indicate a trend toward larger activity spaces over time, consistent with existing literature, whereas the effect in Quebec remains inconclusive – as demonstrated by the mild but not statistically significant coefficient for year in that model.

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