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Neighborhood and Regional Effects on Trip Dispersal: A Case Study using Data from the 9 Largest Metropolitan Regions in Switzerland

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Abstract. The effect of urban form variables on dispersal is explored using activity spaces generated from origin-destination data on 60,000 Swiss residents living in metropolitan areas of varying size, density and population. The diversity of locations enables us to distinguish the roles played by local and regional variations in land use. Parameters are estimated using ordinary least squares (OLS) and simultaneous equation model (SEM) regression analysis. Results indicate that neighborhood type has a large and significant effect on the dispersal of travel by residents, whereas regional effects, found elsewhere to be very large, are quite small. Distance from the core also has a significant impact on dispersal, but only in the first 8 km surrounding the city center. Of the other regional land use variables tested, very few were found to be significant predictors of dispersal, only proportion population within the inner metro area, employment center access and metropolitan area shape. Of note, neither metropolitan area nor population, which were hypothesized to have a significant impact on dispersal, were found to be significant predictors. Finally, the hypothesis of endogeneity in explanatory variables was investigated and rejected. These results indicate that policies aimed at developing dense and mixed urban settlements would carry with them the beneficial effect of reducing travel dispersal, even if not built adjacent to the central business district.

Keywords. Activity space, neighborhood type, metropolitan determinants, simultaneous equation model, urban form.

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1. INTRODUCTION

In the fields of urban planning and travel demand modeling, there is a growing importance placed on the sustainability of travel. Part of this is a growing concern over greenhouse gas emissions (GHG); in Switzerland for instance, the latest figures on transport related GHGs indicate the sector accounts for 32% of the country's total (Office fédéral de l'environnement OFEV, 2012). Another element is the anxiety regarding potential social impacts increases in mobility and motorization may have (McCray & Brais, 2007). These concerns vary widely, from those initially described by Appleyard (1980) regarding the detrimental effects of car traffic on safety and liveability, to questions of equitable access to employment, services and amenities (Kamruzzaman & Hine, 2012). Finally, there are economic concerns, with regard both to the amount spent on providing the infrastructure required for a highly mobile society, as well as that which is spent by individuals and transit operators for the operation of their vehicles (Litman, 2005).

A large body of literature describes the relationships between residence or workplace urban form variables and travel demand measures (Ewing & Cervero, 2010). Tackling the question from a broader perspective, researchers have also looked at differences in travel behaviour between cities to better understand links to regional development patterns; density, development centrality, population size, etc. (Naess et al., 1996; Naess, 2012; Newman & Kenworthy, 1999). To date however, the research which has looked at travel demand in multiple cities has remained aggregate in nature, predicting city-wide VKT, fuel use or mode shares as opposed to predicting them for individuals within those cities. One recent and notable exception to the previous statement would be Nasri and Zhang (2012), who modelled vehicle kilometres traveled by residents in 6 different cities in the US, both as a response to local and regional variables. Their results provide promising evidence that investigated in such a way we may obtain a better picture of the urban-form determinants of travel demand.

While concerns over excessive travel demand can be investigated in various ways, a relatively new means by which this is done is to look at travel behaviour as realized activity spaces. Building upon work carried out in Quebec, Canada (Harding et al., in press), we use the Swiss Mobility and Transport Microcensus 2010 data to investigate the effect of both neighbourhood and regional-level urban form variables on travel dispersal. Research in Quebec using origin-destination (OD) data from three metropolitan areas found neighborhood of residence effects to be significant in all three cases, but more important than these intra-metropolitan differences were differences between cities; notably an apparent correlation between overall city size and travel dispersal. While the average dispersion of households in Montreal was nearly 48km^2, in Sherbrooke (a city with 1/20th the population), the average dispersion was approximately 15km^2.

The Swiss Microcensus, with data on 60,000 residents living in metropolitan areas of varying size, density and population, enables us to distinguish the role that local variations in land use play in explaining dispersal from that of regional attributes. Regression analysis, with the area of the activity space polygon as dependent variable is used to test the hypothesized city-size effect. Potential for residential self-selection biases are also investigated using simultaneous equation modeling (SEM), with SEM and OLS results compared to test for variable endogeneity.

Our results indicate that while some metropolitan variables have a statistically significant effect on dispersal, the most important predictor of travel dispersal remains the neighborhood of residence. Finally, the hypothesis of variable exogeneity is not rejected.

2. THEMES AND LITERATURE

2.1 Urban Form and Travel Demand

In the goal of reducing burden on the reader with respect to background knowledge, few words will be said regarding the broader literature in the field. For an overview of the built environment-travel demand literature, the authors suggest Driving and the Built Environment (Transportation Research Board and Board on Energy and Environmental Systems, 2009), as well as Ewing and Cervero's meta-analyses Travel and the Built Environment (Ewing & Cervero, 2001, 2010). These provide an excellent overview of many of the key issues currently debated as well as where consensus is (or isn't) to be found.

Despite some disagreement, most academics and planners agree on there being links between levels of the 3 Ds (density, diversity and design) and travel demand. Issues of scale, density and distribution then form the crux of the debate on metropolitan indicators (Naess, 2012).

2.1.1 Neighborhood, or clustered, indicators

In addition to individual indicators of the built environment, it is important to understand the reason behind using clustered indicators, or neighborhood types, as explanatory variables affecting travel demand. Clusters are essentially recognition that there exist relationships between multiple dimensions of the built environment, and that interactions can play the role of catalysts or inhibitors. Clusters seek to describe the different types or environments that are present in a way that takes such relationships into account.

Generating neighborhood typologies can be done in different ways, as well as include a variety of components, be it population or employment density, sidewalk provision, transit availability, etc. (see Gershoff et al. (2009) or Miranda-Moreno et al. (2011) for examples).

2.1.2 Metropolitan indicators

Unlike most North American research, which focuses on the properties of neighbourhoods, the work of Naess explicitly explores regional or city-wide aspects to travel demand (Naess et al., 1996; Naess, 2012), as does that of Nasri and Zhang (2012) and, perhaps most commonly cited, Newman and Kenworthy (1989, 1999). The issues discussed are whether certain forms of development, whether urbanization along corridors or high regional density, affect travel demand in the same way the neighbourhood and micro-environmental properties do.

Newman and Kenworthy (1989) analysed data on 32 cities and report a clear relationship between metropolitan density and average fuel use. Their policy recommendation is then a call for reurbanization and densification of cities. Naess et al. (1996), on the other hand, looked at transportation energy consumption in 22 different Nordic towns, making use of multivariate analysis. The authors investigated the influence of population density, size, geometric shape, polycentricism, internal distribution of development, degree of fragmentation and transportation infrastructure supply on transportation energy use; their conclusions also point to density as being the best predictor of energy use per capita, all modes combined (Naess et al., 1996).

While Naess et al. (1996) do not find city size to be a significant predictor of energy use, the authors do comment on this lack of a link, stating that the larger cities are often those with the highest densities at their core (density also found to be the best predictor of energy expenditure for transport). Additionally, dividing the cities into categories using overall size, Naess et al. (1996) find that urban form variables tend to change coefficient estimates depending on which class one looks at. This explains why much of the empirical work conducted in cities the world over has found different effect sizes and even coefficient estimates with opposite signs.

Finally, Nasri and Zhang (2012) also explicitly address the issue of metropolitan-level variables, using data on 6 US metropolitan regions to investigate the relative influence of local and metropolitan built environment descriptors on VMT. Effect sizes are not presented, so while it is difficult to interpret their results, 5 of the 6 metropolitan variables tested emerge as being statistically significant. The estimated coefficients also present intuitive signs, with increases in average block size increasing VMT, while increases in regional employment density, entropy, and population and employment concentration all reducing VMT; i.e. dense, mixed cores with significant shares of the regional population and jobs lead to less vehicular travel.

2.2 Dispersion and activity spaces

As our work focuses on activity spaces as a demand measure, the following section will briefly describe what these spaces are and how they can be interpreted.

Activity spaces can be used for many different purposes, whether to understand access to certain types of amenities or resources (Vallé et al., 2010), transport disadvantage (Kamruzzaman & Hine, 2012) or gender differences (Dijst, 1999). In the context of travel demand modelling, they are most often used as measures of dispersal (Beckman et al., 1983 Harding et al., 2012; Miranda-Moreno et al., 2012).

The actual definition of activity space varies, from a broad concept of locations/spaces one is aware of, to more concrete measurements of spaces one interacts with (action space (Horton & Reynolds, 1970)). In this article, we use the term activity space to mean the spaces individuals travel through on a given day and by association the “area over which they are likely to regularly engage in those activities” (Newsome et al., 1998, p. 361). Understanding what factors come to affect spaces and dispersal, we may then attempt to reproduce the conditions under which beneficial travel patterns emerge.

With respect to measurement, one can use GIS software to produce standard deviational ellipses, standard distance circles, road network buffers or any number of other potential geometries; for an overview of these different outputs, see (Fan & Khattak, 2008; Newsome et al., 1998; Rai et al., 2007.

A fuller history of activity space research is not the focus of this current work, so we merely point the reader in the direction of Schönfelder (2006) for a more complete account.

2.3 Residential self-selection

In order to properly estimate the impact of urban planning interventions, it is important to keep in mind the issue of residential self-selection. Miranda-Moreno et al. aptly describe self-selection as a process whereby "neighborhoods chosen by households correspond with their lifestyle" (Miranda-Moreno et al., 2011), creating a bias in the estimation of the effect of urban form on travel outcomes. Essentially, coefficient estimates for an urban form variable might not actually be measuring the influence of the desired component, but rather the travel demand propensity of individuals who have a preference for a given environment.

Different methods exist to account for this, namely the use of matched pairs (Cao & Fan, 2012) or the joint modeling of household location and vehicle ownership decisions (Miranda-Moreno et al., 2011).

Previous work investigating the impact of neighbourhood types, as a means by which to better evaluate the influence of built form attributes on travel dispersal, found that they are statistically, and in terms of magnitude, significant when modelled at the level of a census metropolitan area (Harding et al., in press). Given the data available nationwide in Switzerland, it is possible to push analysis further and systematically evaluate differences not only between neighborhood types, but also metropolitan areas. By generating descriptors of size, density and structure at the metropolitan level, we can test for significant relationships and measure their impact on overall travel dispersal. Significant coefficient estimates for metropolitan variables would give credibility to the hypothesis of a city size effect.

3. DATA SOURCES AND STUDY AREA

According to the latest census, there are approximately 7.9 million people in Switzerland, of which 4.6 million live within the metropolitan regions we will be analysing data from; namely the urban areas surrounding its 10 largest cities.

Switzerland has a well-developed road network, as well as high levels of public transit and inter-city rail links. 9.8% of individuals in Switzerland have a GA, which gives them access to any inter or intra city public transportation, while 56.5% of people have some form of transit pass, be it a local pass (13.7%) or a half-fare card (38.5%) (Office Fédéral de la Statistique, 2012). This level of market penetration speaks to the large share of the population for which travel without a vehicle is not only made possible by a dense and highly accessible transit network, but is actually chosen.

3.1 Activity Spaces

To generate activity spaces (our measure of dispersion) we use the 2010 Swiss Microcensus on Mobility and Transportation, which contains detailed information on all the trips made by 62,868 persons living in 59,971 households. Of these, 28,293 individuals produced valid activity spaces.

3.2 Built environment descriptors

To generate built environment indicators, population and employment counts, as well as land use data, were obtained from the Bureau Fédéral de la Statistique (BFS); these were available at the hectare level for the entire study region. Categories for land use were aggregated from the 46 NOLU04 categories to four functional types: residential, public buildings, commercial and industrial, and recreational spaces.

For road density we used the OpenStreetMaps link file and filtered out certain categories of roads coded as trails, hiking paths, abandoned, etc.

Finally, to evaluate public transit accessibility, we used the geocoded stop locations for all forms of transit found in the HAFAS database, published by HACON.

These data sources were used in conjunction with the metropolitan area definitions provided by the BFS in their Themakart dataset.

4. METHODOLOGY

4.1 Indicator generation

In order to test the effect of neighborhood of residence on travel dispersal, neighborhood types were clustered using cell-level land use and public transit indicators as inputs, namely: population density, employment density, public transit accessibility and land use mix.

In order to avoid issues of modifiable area unit problem (MAUP), we captured indicator values using a regular grid. This grid was also clipped to the extent of land cover in Switzerland to better account for incomplete cells near the borders of the country, as well as bodies of water. Clipping allowed us to evaluate net as opposed to gross densities, improving the accuracy of values assigned to cells. The size of cells was chosen to be 500 meters in length and width, so as to approximate a 5 minute walk.

Population and employment counts being coded using the coordinate of hectare cells allowed us to aggregate the data outside a GIS environment, simply adjusting for clipped land area.

For transit stop density, HAFAS transit stop locations were intersected with the grid cells.

Finally, an entropy formula was applied to the aggregated functional type areas at the cell level to calculate land use mix (Miranda-Moreno et al., 2011). This approach output values between 0 and 1, where 0 indicates no mix (or only 1 use present) and 1 indicates perfect mix (all 4 uses present in equal amounts).

Two non-cluster built environment indicators generated to be used on their own were distance to nearest core city and employment center accessibility. Generating employment centers involves isolating communes with above average employment densities, employment to resident ratios and high numbers of jobs; a more complete description of the approach can be found in (Harding, 2011).

Once the centers are identified, the formula below is applied to calculate each individual's accessibility to employment centers.

EQUATION 1 Employment Centre Accessibility

- $$ECAccessibility_j = \sum_{i=1}^{n} Empl_i / Dist_{ij}$$

Where:

ECAccessibility$_j$: Employment centre accessibility of household j
Empl$_i$: Number of jobs at employment center i
Dist$_{ij}$: Straight-line distance separating household j from employment center i (in kilometers, minimum value of 1 km and cut-off of 20 km)
n : all employment centers

4.2 Clustering

K-means clustering was employed to generate neighborhood types. The 4 indicator values described in the previous section (population and employment densities, land use mix and public transit accessibility) were standardized and clusters were generated for all cells which had at least 1 non-null value. Calinski-Harabasz values were generated for each number of clusters between 2 and 10 to find an optimal number (Milligan & Cooper, 1985). This resulted in the choice of 4 clusters.

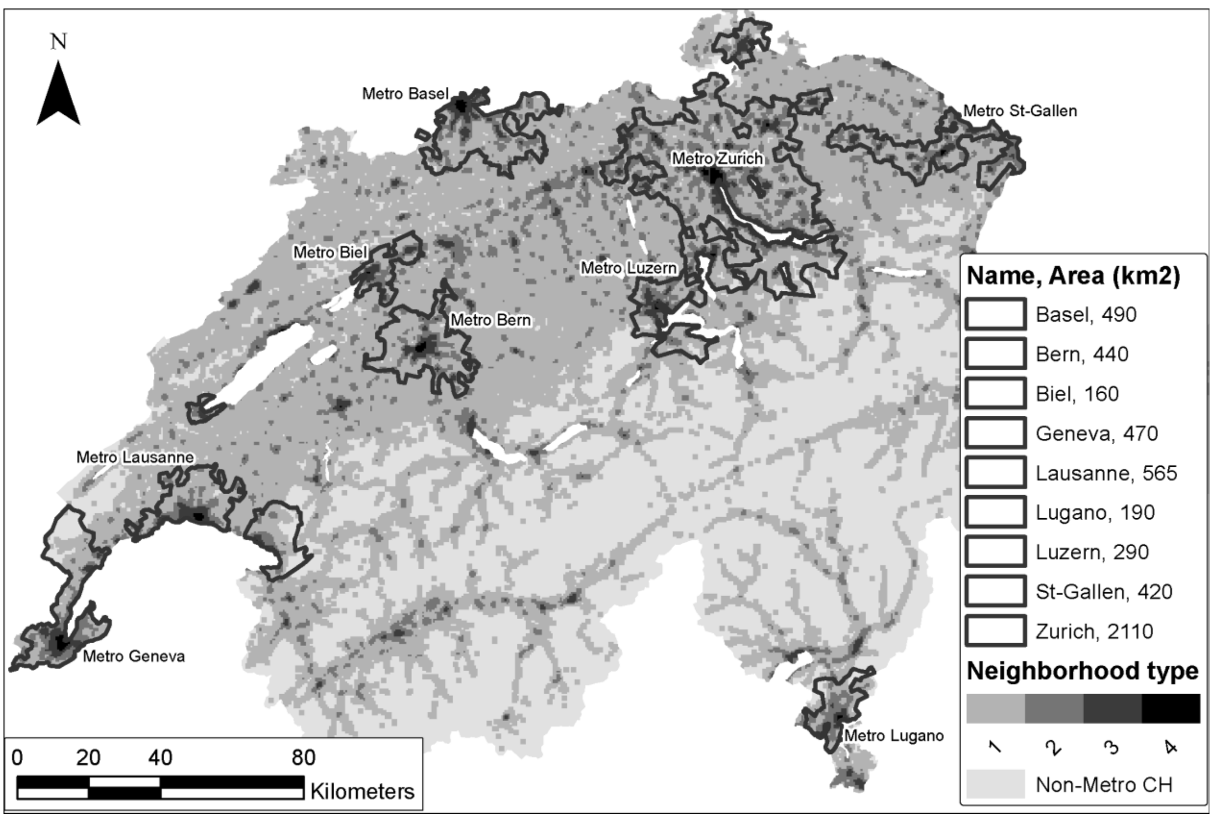

FIGURE 1 Neighbourhood types [Rural (1) to Urban (4)] and metro regions, Switzerland

4.3 Metropolitan Indicators

In addition to defining neighborhood types, metropolitan-level built environment indicators were generated.

Observations were grouped using an altered form of the BFS metropolitan area shapefile definitions. With the 10 largest cities in the country selected, 9 distinct metropolitan areas were obtained (one of the 10 cities, Winterthur, found itself within the broader Zurich metropolitan area). Residents were also defined as being inner or outer-metropolitan in order to test hypotheses discussed in Nasri and Zhang (2012). To ensure compatibility with their analysis, we also used 5 miles (8 km) as a cut-off point.

In order to test for the effect of living in the urban area around a large city, as well as testing for the specific influence of living within or outside the first 5 miles of the core, built environment indicators were generated at both the broad metropolitan scale as well as the inner or outer metropolitan scale. The indicators generated are the following:

> *Total population, population density, total employment, employment density, urbanized area (km^2), proportion metro population within 5 miles of core, proportion employment within 5 miles of the core, land use mix, population concentration, employment concentration, public transit density, road density, and finally individual binary variables for each metropolitan area.*

These were calculated using hectare level land use data and individual transit stop locations.

4.4 Activity Spaces

To quantify dispersion, activity spaces were generated in ArcGIS. Because of the nature of the data (a single day of trips recorded for each individual), minimum convex hull polygons (MCP) were chosen as the output (Harding et al., in press). In order to form a valid activity space, an individual must a) visit at least 3 unique points during the course of the day and b) begin and end his or her day at the primary home location.

Dispersal (polygon area) was calculated directly in ArcGIS, while compactness was obtained using the following formula:

EQUATION 2 - Compactness

$$Compactness_i = Perimeter_{Circle\_i} / Perimeter_{MCP_i}$$

Where:

$Compactness_i$: Compactness of the MCP of individual *i*

$Perimeter_{MCP\_i}$: Perimeter of the MCP of individual *i* (generated using “Calculate Geometry” in ArcGIS)

$Perimeter_{Circle\_i}$: Perimeter formed by a circle having the same area as the MCP of individual *i, or:*

$$2 * \pi * \sqrt{Area_{MCPi}/\pi}$$

Where:

$Area_{MCPi}$: Area of the MCP of individual i (generated using “Calculate Geometry” in ArcGIS)

A compactness approaching 0 would look like a line, whereas a compactness approaching 1 would resemble a circle.

5. RESULTS

5.1 Summary Statistics, largest urban areas

TABLE 1 Summary statistics for the full sample of 9 metropolitan area residents included in our analysis (rural and other urban areas, as well as children, excluded)

Cluster/ Vehicle Ownership	Count	Activity Space Area (km^2)		Dist. Trav. (km)	Compactness	Nb Trips	Full Time Workers	Family with Kids	Active travel	Transit	Motorized	EC Access	Dist from center (km)	Inner metro area	Pop Dens	Job Dens	Transit Stop Dens	Land Use Mix
		mean	*med*	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	ppl/ha	jobs/ha	stops/km^2	(0-1)
C1, No car	122	21.84	*1.61*	45.07	37.4%	4.61	31.1%	49.2%	64.8%	59.0%	57.4%	36,580	14.7	23.8%	4.48	0.88	0.23	6%
C2, No car	962	13.74	*1.03*	36.62	40.7%	4.69	26.8%	40.6%	76.5%	56.2%	36.9%	53,569	13.8	33.6%	15.95	4.85	0.70	24%
C3, No car	2,043	8.35	*0.58*	28.95	42.6%	4.66	24.4%	28.2%	80.4%	61.3%	25.4%	107,803	8.2	65.7%	47.61	20.45	1.84	44%
C4, No car	793	19.02	*0.29*	22.39	46.8%	4.83	28.8%	15.9%	89.4%	57.6%	15.0%	163,718	2.0	97.5%	112.44	97.45	2.76	56%
C1, Car	763	33.66	*6.07*	57.62	43.8%	5.07	44.6%	42.7%	45.3%	9.7%	92.9%	33,771	15.0	20.2%	4.15	0.82	0.24	5%
C2, Car	4,529	34.94	*3.46*	53.51	42.6%	5.10	45.3%	37.9%	50.5%	15.8%	85.6%	47,765	14.1	30.7%	14.64	4.28	0.67	23%
C3, Car	5,230	29.67	*1.76*	45.04	42.7%	5.08	45.9%	30.2%	60.8%	25.1%	72.9%	94,070	9.7	56.6%	43.12	18.05	1.81	42%
C4, Car	1,095	24.68	*0.85*	36.18	45.7%	5.13	48.5%	21.9%	79.0%	39.0%	45.9%	164,190	2.3	96.0%	108.27	97.15	2.76	55%
Total	15,537	26.66	*1.65*	43.71	43.0%	4.99	40.8%	32.3%	63.4%	31.2%	64.1%	85,158	10.4	51.6%	39.64	22.18	1.44	35%

As we can see from the table above, higher value clusters, or more urban neighbourhood types, seem to be correlated with smaller activity spaces. There also exists a clear difference between the travel behaviour of individuals with access to a private vehicle and those without; exactly the type of disparity that could be worrisome if the residents not owning cars are also of a lower income bracket, as this could potentially be indicative of a lack of accessible opportunities for employment/amenities within their activity space.

Compactness is also tied to what neighborhood one lives in, with more compact (or circular) activity spaces being produced by individuals living in more urban areas. This may hint at the fact that it is more likely that individuals living near high densities of amenities, or who are used to traveling around in such environments are also more apt to chain their activities locally when they can (Horton & Reynolds, 1970). Different types of shops located in a spatially proximate way enable one to chain together short, walkable trips into complex tours, maximizing the utility of active and local travel (Ho & Mulley, 2013). Higher trip-making in more urban clusters would also tend to indicate that rather than forcing individuals to travel less because of the traffic present in urban environments, the high density of activity locations simply brings activities closer to the home, reducing the cost of making trips.

In addition, although there are fewer families with children (and by association children and teens interviewed) in the urban type neighborhoods, the rate of active travel is still significantly higher there than in more suburban settings.

The descriptors of urban form and transit accessibility also exhibit stark differences between the more urban and more rural neighborhoods, job density increasing fourfold from cluster 3 to 4 for example. And while there is a relationship between the location of neighborhoods within the city and their degree of urbanity, there are still pockets of urban type neighborhoods further afield.

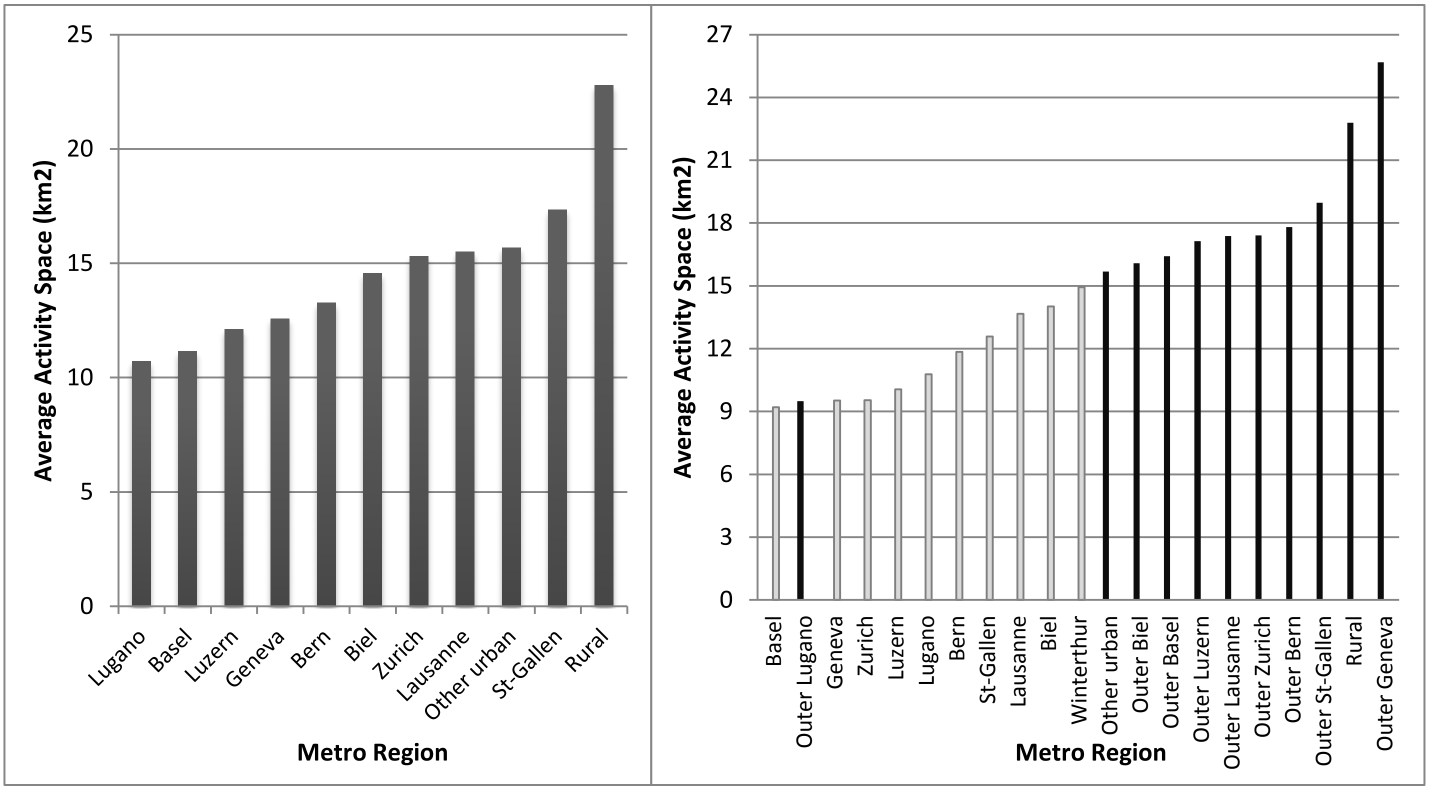

FIGURE 2 Average dispersion by metro region and by inner and outer regions separated - Switzerland MZ2010, top and bottom 1% removed - *Inner metro areas = within 5 miles of the city center and displayed in white, outer areas in black

With regard to our prior hypothesis of a correlation between city size and dispersion, if results had mirrored those obtained in Quebec, the differences in average dispersion from one metro area to another would be large, areas varying in both geographic extent and population from the highs of Zurich (1.9 million people and 2,108 km^2) to the lows of Biel or Lugano (approximately 130 thousand people and 150 to 200 km^2).

As the left portion of the histogram above demonstrates however, this trend did not materialize. Biel finds itself near the middle with respect to average activity space, while Zurich has an average only slightly larger and St-Gallen, one of the smaller urban areas in the country, has a very high average dispersal.

Looking at residents of inner metropolitan areas versus outer metropolitan areas, one begins to understand that the overall size of the metro region may be far less important than living near or far from the core. The right portion of the histogram shows this clear distinction It should also be noted that “Outer Lugano” accounts for only 14 of the 286 valid Lugano metro region activity spaces, which explains its odd situation in the figure.

What would seem to be correlated with dispersal in Switzerland is then not the absolute size of the metropolitan area, but rather density in a given environment (whether inner or outer area, urban or rural); consistent with the findings of Naess (2012).

One last element included in our analysis was the shape and distribution of development, quantified in three different ways:

Percent CVH polygon occupied = percent of the convex hull polygon surrounding the metropolitan area occupied by urbanized area

Percent circle occupied = percent of the smallest possible circle formed around the metropolitan area that is occupied by urbanized area

CVH polygon compactness = compactness of the convex hull polygon encompassing a metropolitan area's urbanized area

5.2 Regression Analysis, largest urban areas

As correlation does not imply causation, we used ordinary least squares, as well as a simultaneous equation model (SEM) regression, to assess the influence of multiple variables on dispersal.

The way the SEM is structured to account for variable endogeneity and self-selection bias is as follows: certain demographic variables thought to influence both the dispersion of travel and the likelihood of choosing to live in one or another type of environment are used as treatment variables in neighborhood and vehicle ownership choice, as well as being included as explanatory variables affecting dispersion. The dependent variable is the logarithm of the area of the activity space polygon. This is the same approach used in (Miranda-Moreno et al., 2011), as well as (Harding et al., in press)

Coefficient estimates are provided below, with ordinary least squares (OLS) and simultaneous equation model (SEM) results presented side by side to allow comparison. Variables included as treatments in the logit portion of the SEM are indicated below the table.

TABLE 2 OLS and SEM model estimates; the dependent variable is the logarithm of the activity space area (m^2).

			SEM			OLS		
	Var		Coeff	z-stat	Prob	Coeff	t-stat	Prob
No Car	Clus1	*(more rural)*	-0.547	-2.45	0.01	-0.649	-3.54	0.00
	Clus2	|	-1.129	-7.06	0.00	-1.176	-10.32	0.00
	Clus3	↓	-1.984	-11.58	0.00	-1.476	-13.55	0.00
	Clus4	*(more urban)*	-1.775	-10.56	0.00	-1.854	-13.64	0.00
Car	Clus1	*(more rural)*		omitted			omitted	
	Clus2	|	-0.960	-5.28	0.00	-0.427	-4.60	0.00
	Clus3	↓	-0.771	-5.21	0.00	-0.906	-9.52	0.00
	Clus4	*(more urban)*	-1.533	-9.45	0.00	-1.503	-11.92	0.00
	Leisure (binary)		0.537	10.48	0.00	0.537	10.45	0.00
	Maintenance (binary)		-0.544	-11.22	0.00	-0.543	-11.19	0.00
	Work (binary)		0.365	7.22	0.00	0.364	7.27	0.00
	Child (binary) - under 15		-1.616	-16.52	0.00	-1.596	-16.87	0.00
	Elderly (binary) - 75+		-0.274	-3.25	0.00	-0.276	-3.65	0.00
	Full-time worker		0.199	3.86	0.00	0.203	4.11	0.00
	Male (binary)		0.235	5.76	0.00	0.242	6.05	0.00
	Retired (binary)		-0.388	-2.14	0.03	-0.386	-2.13	0.03
	Self-employed (binary)		-0.293	-3.79	0.00	-0.292	-3.77	0.00
	Student (binary)		-0.141	-1.95	0.05	-0.179	-2.51	0.01
	Tenant (binary)		-0.199	-4.12	0.00	-0.134	-3.26	0.00
	University educated (binary)		0.159	2.98	0.00	0.205	4.00	0.00
	Saturday (binary)		0.443	7.36	0.00	0.442	7.35	0.00
	Sunday (binary)		0.395	5.34	0.00	0.394	5.32	0.00
	High income (binary)		0.163	2.89	0.00	0.161	2.88	0.00
	Low income (binary)		-0.188	-3.08	0.00	-0.198	-3.41	0.00
	Family with kids (binary)		-0.166	-3.44	0.00	-0.179	-3.76	0.00
	Nb cars per person		0.387	7.21	0.00	0.396	7.41	0.00
	Prop metro pop w-in 8km of core		-0.461	-2.78	0.01	-0.469	-2.83	0.01
	Age		-0.014	-7.32	0.00	-0.014	-8.81	0.00
	Distance from inner-outer border (km), inner metro only		-0.051	-4.24	0.00	-0.050	-4.18	0.00
	ECenter access, 20km adj. (1,000s)		0.001	4.00	0.00	0.001	3.97	0.00
	Metro MBCircle radious (km)		-0.008	-1.94	0.05	-0.008	-1.95	0.05
	Nb stores visited		0.127	6.37	0.00	0.128	6.41	0.00
	Nb trips		0.216	18.75	0.00	0.215	18.67	0.00
	Constant		14.762	62.61	0.00	14.545	64.03	0.00

Nb Obs.	16,838	16,838
R-Sq	0.066	0.193
Adj. R-Sq / Pseudo R2 MNL	0.146	0.191
AIC	127,413	76,705
Logit AIC	~	50,632
Sum AIC	127,413	**127,336 (-76)**

Treatment Variables
Full-time worker
Part-time worker
Low income (binary)
High income (binary)
University educated (binary)
Student (binary)
Male (binary)
Retirement aged (binary) - 65-74
Elderly (binary) - 75+
Age
Tenant (binary)
Family with kids (binary)
Single person household (binary)
Single parent (binary)
Non-family household (binary)

To establish which was a better model (in terms of efficiency and fit), we compared the Akaike information criterion (AIC) value generated by the SEM to the combined AIC values of the OLS and a multinomial logit (MNL) with the same composition as the treatment in the SEM. i.e. In addition to measuring the AIC value generated by the OLS, we estimate a MNL model for cluster/car choice using the SEM's treatment variables and add its AIC value to that of the OLS. Again, this approach was also used in (Miranda-Moreno et al., 2011).

Lower AIC values indicate more efficient models, so the higher value generated by the SEM indicates that the simultaneous equation modeling approach is less efficient that the OLS and MNL combination. While this does not mean that SEM coefficient estimates are wrong, efficiency being higher for the OLS we cannot objectively reject a hypothesis of variable exogeneity for explanatory variables, or otherwise conclude that there is self-selection bias resultant from using neighborhood-and-vehicle-ownership choice variables.

Putting aside the issue of variable endogeneity, both models estimate significant, intuitive and right-sided neighborhood type coefficients for all cluster-car combinations. R^2 is also comparable to similar work done in Quebec (Harding et al., in press).

With regard to the other variables of interest, distance from the center was first run unaltered, but found to be insignificant when other variables were included. An altered indicator however, whereby only inner-metro residents' distance to cores was calculated did prove significant and is included in the model. This would indicate central city access is important, but only up till a certain point. Distance was of particular interest as it relates to the city size hypothesis of dispersal; i.e. if increasing distance from the core were shown to lead to more dispersed travel, ceteris paribus, an argument could be made that reigning in urban development and promoting compact cities would lead to lower aggregate travel demand.

The rest of the variables in the model, are all significant and right-sided. Vehicle ownership and more rural type neighborhoods both lead to increased dispersal of travel, while making work, school or leisure trips all increase the activity space of individuals - leisure having the largest influence. Maintenance on the other hand, which could be described as trips made to get groceries or other goods needed for the household, lead to smaller activity spaces; these trips cut into the time budget of individuals, but do not involve coordinating activities with others or travel to new locations for novelty. Work or school, on the other hand, may be located far away from the home, because finding employment in most fields causes one to travel outside one's neighborhood, and because the location of universities and higher education institutions are usually centralized.

Full time workers lead to larger activity spaces, as do high income individuals. This is consistent with MZ2010 results (Office Fédéral de la Statistique, 2012). The finding that households travel more on the weekend is interesting to an outsider living in Switzerland (co-author Harding), as most stores close early on Saturday and very few are open at all on Sunday. There are, by contrast, fewer time constraints on these days, making it possible to travel further out for leisure than during weekday evenings.

The fact that including distance from center in the model does not affect cluster coefficients or significance in any meaningful way is also interesting in contrast to the statements made in Naess' meta-analysis (2012), where he states that

> *"clear correlations were found between local-area density and most travel behaviour variables when controlling only for demographic and socioeconomic variables, but not for the location of the dwelling relative to the city center. Once the latter variable was included in the analysis, the effects of local-area density vanished or were substantially weakened"* (Naess, 2012, p. 28)

The effect sizes estimated for all statistically significant variables, other than distance from the core, would seem to indicate that we have isolated variables with a large influence on the overall dispersion of peoples' daily travel.

Overall, testing for the influence of metropolitan descriptors such as density, employment concentration, population size, urbanized area, road density, etc., gave surprising results - few variables emerging as significant predictors of travel demand, and for those that did, the effect sizes were not of the order of magnitude expected.

TABLE 3 Effect size of variables in regression model for Switzerland

	Var		OLS Coeff.	Mean	Effect	Effect Type
No Car	Clus1	*(more rural)*	-0.322	0.014	-27.5%	0 / 1
	Clus2	|	-0.937	0.090	-60.8%	0 / 1
	Clus3	↓	-1.282	0.153	-72.3%	0 / 1
	Clus4	*(more urban)*	-1.844	0.053	-84.2%	0 / 1
Car	Clus1	*(more rural)*		*Omitted*		*Omitted*
	Clus2	|	-0.282	0.269	-24.6%	0 / 1
	Clus3	↓	-0.811	0.311	-55.5%	0 / 1
	Clus4	*(more urban)*	-1.339	0.065	-73.8%	0 / 1
	Child (binary) - under 15		-1.616	0.077	-80.1%	0 / 1
	Elderly (binary) - 75+		-0.274	0.128	-24.0%	0 / 1
	Family with kids (binary)		-0.166	0.363	-15.3%	0 / 1
	Full-time worker		0.199	0.377	22.0%	0 / 1
	Leisure (binary)		0.537	0.798	71.1%	0 / 1
	Low income (binary)		-0.188	0.137	-17.2%	0 / 1
	Maintenance (binary)		-0.544	0.630	-42.0%	0 / 1
	Male (binary)		0.235	0.466	26.5%	0 / 1
	Retired (binary)		-0.388	0.011	-32.1%	0 / 1
	Saturday (binary)		0.443	0.115	55.7%	0 / 1
	Self-employed (binary)		-0.293	0.062	-25.4%	0 / 1
	Student (binary)		-0.141	0.084	-13.1%	0 / 1
	Sunday (binary)		0.395	0.076	48.5%	*0 / 1*
	Tenant (binary)		-0.199	0.552	-18.0%	0 / 1
	University educated (binary)		0.159	0.175	17.3%	0 / 1
	Work (binary)		0.365	0.414	44.1%	0 / 1
	Nb cars per person		0.387	0.527	48.8%	½ → 1 car
	Age		-0.014	45.577	-6.8%	Mean + 5 years
	Nb stores visited		0.127	0.704	13.6%	Mean + 1 store
	Nb trips		0.216	5.006	24.1%	Mean + 1 trip
	Prop metro pop w-in 8km of core		-0.461	0.515	-4.5%	Mean + 0.10
	Dist inner-outer border (km), inner only		-0.051	4.355	-5.0%	Mean + 1 km*
	EC access, 20km adj. (1,000s)		0.001	84.146	15.7%	Mean to p75
	Metro MBCircle radius (km)		-0.008	23.460	-1.9%	Mean + 10 %
	Constant		14.762	14.76188	N/A	N/A

* Indicates getting 1 km closer to the core

Because some of the variables are binary and others continuous, results are presented grouped in blocks. In the first part, the effect size reported is the difference between the presence and absence of a binary variable (1/0), whereas the second portion has to be read differently.

The effect of age was quantified by adding 5 years to the mean (producing a decrease of 7% to the area of activity space);

the effect of cars per person is the difference between having to share a car (0.5 cars per person) and having a car to one's self;

while number of trips and number of stores visited represent the effect of adding one to the mean value in either field.

As for the four metropolitan-level variables:

proportion population within 5 miles (a measure of metropolitan concentration) has the effect of a 5% decrease in dispersal for a 0.10 increase in the variable value - i.e. higher population concentration at the core means less average dispersal for residents in the metropolitan area;

distance from inner-outer border was estimated to lead to a 5% reduction in dispersion for every kilometer one nears to the core, or a maximum difference of 40% from the edge to the city center;

EC access (measured from the home location to nearby employment centers, see EQUATION 1) was estimated to lead to an increase of 15% from mean (82,521) to 75th percentile (129,470);

and Metro MBCircle radius (a measure of the radius of the smallest possible circle capable of containing the urban area of a metro region) is estimated to decrease the average dispersal of travel by 1.9% for a 10% increase in radius.

6. DISCUSSION

According to our model estimates, the ideal city from a travel demand perspective would have most if not all its population within the inner metro area (prop pop inner metro), clustered as close as possible to the core (high distance from cut-off), while having the lowest possible values for employment center access (which could be made possible by having a good mix of employment and residential land uses in each commune), and finally a large overall MBCircle radius, or large overall urban area. The last is the only metropolitan variable which is hard to make intuitive sense of, except to say again that large metropolitan areas (like Zurich (1), Lausanne (2) and Geneva (4)) are also high density urban areas with low dispersion among inner metro residents.

Regarding the metro variables, one can imagine that the proportion of residents in the inner area affects everyone in a metro region in ways similar to those hypothesized for metro population or area: the more people live far out, the higher the likelihood that residents' social networks contain both inner and outer residents, making joint leisure, and other trips, harder to coordinate and likely to be more dispersed.

Also, while focus is on neighbourhood and metropolitan effects, coefficient estimates for our control variables, it should be noted, are intuitive and right-sided. Effect sizes for the variables are considerable as well, not being simply statistically, but also in terms of magnitude of effect, significant.

Reading only Table 3 and drawing from it the conclusion that *compact cities* are a highly effective metropolitan-level policy solution for containing overall travel dispersal would be potentially erroneous however. Although from a sustainability perspective, the authors find no problem with densifying the cores of cities and limiting sprawling development at the fringes, two caveats should be mentioned. First, while the above logic is a valid reading of the regression model estimates for proportion population within 5 miles/8 kilometers, we also attempted to include metropolitan area and metropolitan population/jobs as variables to no avail. Hence, the relationship is more complex than simply identifying some size beyond which cities should not grow and where they should instead branch off. Second, while the effect size for "proportion population within 5 miles" seems reasonable for consideration (an increase of 10% to the proportion of residents living in the inner area leads to a decrease of 4.5% in the dispersal of residents), the sample minimum and maximum values (Zurich with 28.7% of its population within the first 5 miles and Lugano with 95.2%) lead to a maximum effect of 26.4%.

As such, the take-away message seems to be that there may very well be a "city size" component to travel dispersal, but that when tested using consistent, national datasets, this component is smaller than what it appeared when merely comparing results from three different data collection efforts in Canada. Distance from the core to a certain threshold has been found to affect dispersal, but after this point (8 km) there is no longer any significant effect. This finding diminishes the importance afforded to overall city size as cities and metropolitan areas around the world continue to swell in size, and a smaller and smaller portion of the global population is likely to live in metropolitan areas of less than 5 miles in radius (Florida, 2008).

Neighborhood type on the other hand, would seem to account for an overwhelming proportion of the dispersion of individuals, so whereas small cities on a scale that allows for most travel to be made by active modes are decreasing in their share of national population, dense, mixed and transit accessible neighborhoods can be built anywhere and are estimated to reduce the dispersion of residents' daily travel by up to 80 or 85%; no small feat. This means that a great importance should be placed on the environments we choose to build, no matter where they are situated, as a wealth of local employment and leisure opportunities, and neighborhood amenities seem to reign in excessive travel.

7. CONCLUSION AND FUTURE WORK

Neither metropolitan size nor population had the expected effect on overall dispersal, but distance from the core was found to be a statistically significant predictor of travel dispersal, if only up to a certain distance. What this means, along with the strong effect sizes found for urban neighborhood types (high densities, land use mix and public transit access combined), is that policies aimed at building compact, dense and mixed urban settlements would carry with them the beneficial effect of reducing travel dispersion, even if they are not built within blocks of historic city cores.

What would be another considerable step forward in understanding sustainable travel behavior, would be to integrate the dimension of GHG emissions to analysis of activity spaces and dispersion. Other authors have already modeled the effects of land use and vehicle technology on emissions, but with respect to addressing the explicit links between GHGs and dispersion, there is little work already done, let alone generated with as large a sample as a national survey.

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