Sizing up transport poverty: a national scale accounting of low-income households suffering from inaccessibility in Canada, and what to do about it

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Abstract

Millions of Canadians rely on public transportation to conduct daily activities and participate in the labour force. However, many low-income households are disadvantaged because existing public transit service does not provide them with sufficient access to destinations. Limited transit options, compounded with socioeconomic disadvantage, can result in transport poverty, preventing travel to important destinations, like employment opportunities. Given the growing gentrification of Canadian downtowns and the dispersion of poverty into Canadian suburbs, the time is right for a national accounting of those living in transport poverty, and the development of a national transport and land use strategy for alleviating the risks of accessibility deprivation. Accordingly, in this paper we measure and analyze vertical inequalities in access to employment in Canadian cities in order to estimate how many, where, and to what extent, Canadians are at risk of transport poverty. We make use of open transit network data and cutting edge accessibility measurement methods to generate comparative scores suitable for a national-scale analysis. We find that in aggregate, lower income neighbourhoods tend to have better levels of transit accessibility. But despite this overall positive outlook, there are still nearly one million low-income individuals living in urban areas with low transit accessibility. We summarize our findings by generating descriptive typologies for areas vulnerable to transport poverty which are then used to develop and recommend planning strategies to reduce inequalities.

1 Introduction

Public transit is paramount in providing many urban residents around the world with the ability to travel to daily activities and participate in the labour force. Especially within lower income groups, transit is often the only means for accomplishing independent travel. Despite this reliance, many neighbourhoods are disadvantaged because public transit does not provide all places with sufficient access to destinations, like employment opportunities. Poor transit accessibility, combined with other forms of social and economic disadvantage (e.g. poor health, not being able to afford a car, etc.), can result in transport poverty (Casas, 2007; Preston & Rajé, 2007; Lucas, 2012). This can limit people in their ability to find employment opportunities and participate in the labour force. In Canada, governments are currently investing billions of dollars in public transport with very little guidance on whether and how this infrastructure can be used to achieve a higher degree of transport justice in Canadian cities. Social equity and inclusion are part of provincial and municipal policy goals across the country (Government of Canada, 2017), but to date there has been no attempt to understand the scale of transport poverty at a national scale. To address this knowledge shortcoming, the objectives of this paper are threefold:

1. Measure transit access to employment for Canada's eight largest cities to analyze inequalities in accessibility with respect to socioeconomic status (SES).
2. Estimate where and to what extent Canadians are at risk of transport poverty.
3. Generate neighbourhood-level typologies for areas vulnerable to transport poverty in order to recommend urban planning strategies aimed at reducing risks of transport-related exclusion.

Our findings show that low SES residents are generally more centrally located and have relatively higher levels of transit accessibility. Despite this positive outlook in aggregate, there are still a substantial number of low SES Canadians who are living in areas with low transit accessibility. We estimate the number of Canadians at risk of transport poverty by counting low income or otherwise vulnerable residents who are living in the lowest areas of transit accessibility. We find that within Canada's eight largest cities, 5% of the total population are living in low income households which are also situated in areas with low transit accessibility. This totals to nearly one million people who are at risk of transport poverty nation-wide.

Through a cluster analysis approach, we generate descriptive typologies of transport poor neighbourhoods. We find that transport poverty is most apparent in very dense, low-income, tower-neighbourhoods located off of the main axes of transit supply, or wherever low income populations live in low-density suburban urban forms across the nation. We use these findings to recommend policy and urban planning strategies directed towards improving transit accessibility and reducing risks of trans-

port poverty in Canadian cities. Policy recommendations include focusing future transit investments in areas which have high concentrations of low income households and low levels of transit accessibility, intensification and diversity of land-use to increase accessibility and reduce commute distances, as well as a consideration of subsidizing ride-sharing or implementing demand-responsive transit in low density areas.

This is the first time, from our knowledge, that an accounting of transport poverty has been conducted at a national scale anywhere in the world. And since concerns of transport poverty are escalating internationally, the methodologies described in this paper can inform studies in other countries as well. The policy recommendations in this paper can also provide guidance for urban areas outside of Canada since Canadian cities are quite similar in terms of urban form and transportation issues to some cities in the United States, Australia, and Europe.

2 Background

2.1 Inequalities in Transport Accessibility

A primary function of an urban transport system is to provide people the opportunity to participate in daily activities, social interactions, and access to destinations necessary for their well-being. The concept of accessibility is commonly used to assess the distribution of benefits of urban transport systems. Accessibility can be understood as the ease of reaching destinations (Hansen, 1959) and is increasingly being used to evaluate transport plans and land use policy (Papa et al., 2014; Merlin et al., 2018). In modern cities, greater levels of accessibility have been significantly associated with shorter commuting times (Kawabata & Shen, 2007; Hu, 2015), increased employment rates (Sanchez, 1999; Merlin & Hu, 2017), greater levels of activity participation (Paez et al., 2009; Cordera et al., 2017), and it can foster social inclusion and reduce social isolation (Garrett & Taylor, 1999; Lucas, 2012).

The distribution of land-use and transportation networks in cities is never spatially uniform. Therefore, access to destinations is never equal among urban populations. While some inequality is inevitable, particularly low levels of accessibility can potentially result in transport poverty. Transport poverty occurs when transport disadvantage (not having access to a car, poor public transit options, etc.) compounds with other forms of potential social disadvantage (unemployment or low income, disability or poor health, etc.) (Lucas, 2012). Transport poverty is the compounded lack of ability to travel to important destinations and activities. This can result in an increased generalized cost of reaching destinations, suppression of activity participation, and, in the worst cases, can result in the perpetuation of social exclusion (Casas, 2007; Preston & Rajé, 2007; Pereira et al., 2017).

From a justice perspective, the normative argument for reducing inequalities is often framed through a moral lens of social equity. At a basic level, social equity refers to the fairness with which impacts (i.e. benefits and costs) are distributed. For transport policy, social equity is usually framed towards providing equality of opportunity (e.g. to access destinations) rather than of outcome (Litman, 2003). Recent approaches for investigating social equity in transport have included drawing upon Walzer's *Spheres of Justice* (Walzer, 1983) and Rawls' *A Theory of Justice* (Rawls, 1971) to advocate for increasing the average accessibility in a region while at the same time reducing the gap between the highest and lowest levels of accessibility (Martens, Golub, & Robinson, 2012; Martens, 2016; Pereira et al., 2017).

Assessing the equity of transport systems is often approached by framing equity in terms of horizontal or vertical dimensions (Litman, 2002; Delbosc & Currie, 2011; Pereira et al., 2017). Horizontal equity is concerned with the distribution of a resource, like transit provision, equally amongst the overall population. Vertical equity pertains to the distribution of a resource with focus towards specific groups, often those who are more vulnerable to social or economic exclusion. As it pertains to transportation, vertical equity is often studied in relation to income and social class (Litman, 2002; Welch & Mishra, 2013). In other words, vertical equity is focused on analyzing the compounding factors that can result in transport poverty. There have been a plethora of studies which have measured inequalities in accessibility among the overall population and comparing with various subgroups, who are potentially more vulnerable to experiencing transport poverty. Some studies have found differing levels of accessibility for minority groups (Parks, 2004; Klein et al., 2018), recent immigrants (Blumenberg, 2008; Farber et al., 2018), single-parent families (Páez et al., 2013), by age cohorts (Delbosc & Currie, 2011; Barnes et al., 2016), by gender (Hanson & Pratt, 1995; Klein et al., 2018), or by wages and income levels (Delbosc & Currie, 2011; Fan et al., 2012). Other studies have generated combined measures of socio-economic disadvantage at a neighbourhood level to compare with accessibility measures to highlight where gaps in transit accessibility align with social need (Foth et al., 2013; Fransen et al., 2015). Research has also shown that the travel modes available to an individual makes a substantial difference in terms of access to destinations, particularly the disparity between transit riders and those who have regular use of a private vehicle (Benenson et al., 2011; Golub & Martens, 2014; Benenson et al., 2017). There have been a number of academic reviews which have discussed how social equity, and in particular improving people's access to destinations, should be further incorporated into transportation plans and policy to reduce inequalities and foster social and economic inclusion (Wee & Geurs, 2011; Karner & Niemeier, 2013; Manaugh et al., 2015; Pereira et al., 2017).

Access to employment opportunities in particular has been a key indicator for evaluating the performance and social outcomes of a city's transport network (Shen, 1998; El-Geneidy & Levinson, 2006; Bania et al., 2008). Employment is paramount

to preventing social exclusion as it provides the financial ability to support other aspects of life. The ability to obtain and retain employment can depend on a number of factors like education, social network, and size and proximity to the labour market. Difficulties in finding employment can be compounded if local transit service is ineffective in providing access to destinations in a reasonable amount of time (Kain, 1992). Some recent studies have examined how lower levels of transit accessibility can negatively affect employment outcomes (Sanchez, 1999; Allard & Danziger, 2002; Merlin & Hu, 2017). In a survey in the UK, two out of five unemployed citizens link difficulties in finding employment with the inability to use a car and insufficient public transit options (Social Exclusion Unit, 2003). Other studies have not found a significant relationship with job access and employment outcomes. For example, Sanchez, Shen, and Peng (2004) found no association between transit access and employment status of welfare recipients in six American cities. Access to employment by transit is also associated with transit mode share (Owen & Levinson, 2015; Boisjoly & El-Geneidy, 2016), indicating that if transit accessibility is improved for an area, then it could encourage a mode shift away from private vehicles and have other environmental and economic benefits like reducing congestion and emissions. Jobs accessibility is also a good proxy for access to other types of destinations as the location of jobs are highly correlated with other key activity destinations like shops, services, and recreation.

2.2 Accessibility Research within the Canadian Context

In recent decades, Canada has witnessed a rise in socioeconomic inequalities, and concentrations of poverty, both at a regional level (Breau, 2015) and within cities (Hulchanski et al., 2010; Walks & Twigge-Molecey, 2013; Breau et al., 2018). Along with this growth in poverty, evidence has indicated that poverty distributions have become more suburbanized; increased costs of housing in city centres have pushed lower-income residents to more affordable, but less accessible areas (Ades et al., 2012, 2016).

Moreover, several Canadian research projects have found that people living in areas with low accessibility have significantly lower activity participation rates, particularly for those who are socially disadvantaged in other ways. For example, McCray and Brais (2007) examined how transportation factors limit the daily activity patterns of low income women in Quebec City. Spinney et al. (2009) showed there is significant association between transport mobility benefits and quality of life for elderly Canadians. Allen and Farber (2018) analyzed how low accessibility limits the on-campus participation of University students. A series of papers from the same research effort used large-scale travel surveys and spatial econometric models of travel behaviour to identify how the disparities in accessibility among low income, elderly, and single-parent families dissuaded participation in daily activities (Paez et al., 2009;

Roorda et al., 2010; Páez et al., 2013). Many suburban low-SES households currently have a vehicle which they rely on for daily travel. However, they may still be at risk of transport poverty as they are more sensitive to increasing costs of driving (fuel costs, paying interest on car loans, etc.) which increase the likelihood of not being able to afford a vehicle in the future, meaning they would become reliant on insufficient transit service (Mattioli et al., 2018; Walks, 2018).

The Canadian government is currently investing billions of dollars on transit in aims to relieve congestion, reduce travel times, and increase accessibility. The 2016 federal budget pledged $3.4 billion towards transit investment over the subsequent three years, and in 2017 the Canadian government announced it will invest $20.1 billion over the next decade in public transit through bilateral agreements with provinces (Government of Canada, 2017). Provincial and municipal governments are also investing substantially in transit infrastructure projects. Even though social equity and inclusion are increasingly a part of policy goals in regions across the country, as well as at a national level (Government of Canada, 2017), there is little coordination or guidance as to whether or how these goals can be addressed through investments in public transit infrastructure. We argue that by accounting for the number of transport-poor people across the nation in this paper, we can shed light on the importance for the development of national, provincial, and municipal policy strategies that can be used to steer transport investments in a socially progressive manner.

There has been some previous research in analyzing transit access to employment in Canadian cities, primarily focused in Montreal and Toronto. These existing studies have involved analyzing inequalities in accessibility comparing with socioeconomic status (Páez et al., 2013; Foth et al., 2013; El-Geneidy et al., 2016), incorporating fare costs into accessibility measures (El Geneidy et al., 2016), comparing transit accessibility before and after long-term changes in transportation infrastructure and land use patterns (Foth et al., 2013; Farber & Grandez, 2017), or examining daily fluctuations in accessibility (Boisjoly & El-Geneidy, 2016; El-Geneidy et al., 2016; Wessel, Allen, & Farber, 2017). Overall, this existing work has indicated that lower income neighbourhoods generally have better transit access to jobs than the overall population. Correlation results are however most likely skewed by the large number of affluent suburban neighbourhoods with poor transit accessibility. Despite this positive outlook in aggregate, there are still potentially large numbers of low income suburban households lacking sufficient access to employment that are not being accounted for. A report on social inclusion in transport planning in Canada estimated that a third or more of households in Canada have at least one member who is transport disadvantaged (Litman, 2003). And while ample research has linked transport disadvantage with activity participation and well-being (Spinney et al., 2009; Paez et al., 2009), there is little existing detailed knowledge on the scope of the national transport poverty problem, and how it is distributed within and between Canadian

cities. This means that existing policy does not have a clear understanding of how to funnel transit investment into projects that reduce inequalities in transit accessibility. The following sections detail analyzing inequalities in transit accessibility and quantifying the extent of transport poverty in Canada's eight largest cities.

3 Study Regions & Data

This study looks at the eight most populous metropolitan regions in Canada. Additively, these have been referred to as urban megaregions (Simmons & Bourne, 2013). For our study, we use household demographic and employment data from the 2016 Canadian census. From the 2016 Canadian census, 58% of Canadians live in the eight study regions. The boundaries of these regions for our study are composed from Census Metropolitan Areas (CMA). CMAs are agglomerations of municipalities which pertain to urban areas with a population of over 100,000 where at least 50% of the employed labour force works in the region's core (Statistics Canada, 2016a). For our study, any adjacent CMAs are merged due to the commuting flow and transit agencies that link adjacent regions together. See Table 1 for summary statistics of each urban region.

For our analysis, we use a measure of competitive access to employment. Competitive measures of access to employment allow for comparing between regions by accounting for competition both among the labour force for jobs as well as competition among employers for employees (Geurs & van Eck, 2003; Merlin & Hu, 2017). These measures were computed at the census Dissemination Area (DA) level using 2016 census demographic and employment data (Statistics Canada, 2016b). DAs are the smallest geography in which demographic and socio-economic data are released for the Canadian census. Competitive access to employment measures were calculated as follows.

$$A_{i,T} = k|120|^{-1} \sum_{\tau \in M} \sum_{j=1}^{J} \frac{O_j f(t_{i,j,\tau}) f(t_{i,j,\tau})}{L_j} \tag{1}$$

$$A_{i,D} = k \sum_{j=1}^{J} \frac{O_j f(t_{i,j,d}) f(t_{i,j,d})}{L_j} \tag{2}$$

$$L_j = |120|^{-1} \sum_{\tau \in M} \sum_{i=1}^{I} \frac{\alpha_{i,T} P_i f(t_{i,j,\tau})}{A_{i,T}} + \sum_{i=1}^{I} \frac{\alpha_{i,D} P_i f(t_{i,j,d})}{A_{i,D}} \tag{3}$$

$A_{i,T}$ is the measure of location i's access to employment by transit, and $A_{i,D}$ is a measure of access to employment by driving. O_j is the number of jobs at j. L_j

is a measure of access to the labour force from work location j (i.e. the number of workers in the catchment area of a place of employment). P_i is the size of the labour force at i. $t_{i,j,d}$ and $t_{i,j,\tau}$ are travel times by driving and transit during the morning commute period. Travel times were computed using OpenStreetMap and GTFS data. As in other studies (Owen & Levinson, 2015; Farber & Fu, 2017), travel times by transit were computed for every minute, τ, during the morning commute period M (7:00am to 8:59am), and then averaged to account for fluctuating transit schedules. The impedance functions for transit and driving, $f(t_{i,j,\tau})$ and $f(t_{i,j,d})$, use an inverse-power decay function parametrized such that a 30 minute commute returns a value of 0.5, and with a maximum value of 1 (at $t_{i,j} = 0$). 30 minutes is approximately the average commute duration across all eight regions (Statistics Canada, 2016b). The two $f(t)$ terms in A_i permit accurate comparison between cities which have differing transport networks and sub-optimal distributions of opportunities (Delamater, 2013). $\alpha_{i,D}$ is the commute mode share ratio of workers at location i who travel to work via private vehicle. $\alpha_{i,T}$ is the mode share ratio by transit and walking. The mode share for transit for our study is assumed as the total non-driving commuting population ($\alpha_{i,T}$ = 1 - $\alpha_{i,D}$), and therefore also includes the small percent of those who take active modes (bike or walk). This assumes that those who bike or walk to work are also able to commute to work by transit, but not by car. The resulting values of $A_{i,T}$ and $A_{i,D}$ are scaled (via the parameter k) from 0 to 1 to provide easier interpretation, where 0 is no access and 1 is the maximum level of access to employment observed for any travel mode across Canada (URL blinded for review).

Accessibility was computed for access to all jobs in each region as well as access to jobs by different income levels in order to examine if there is a greater mismatch between low-income workers and low-income jobs. When computing access to jobs stratified by income level, O_j and P_i pertain to jobs and the labour force within the specified income range. The income ranges are split at $10,000 intervals of yearly after-tax individual income (Statistics Canada, 2016a).

There are two potential limitations regarding the accessibility measures used in this study. One is that the spatial distribution of actual jobs seekers and job openings could vary from the overall population and employment surfaces (Fransen et al., 2018). However, we only had available data for the overall labour force and the total amount of employment in these regions. From our knowledge, comprehensive data for job seekers and openings does not exist Canada-wide. Another limitation is that we do not consider the monetary cost of travel. Some transit agencies have greater fares than others which could deter travel, particularly for lower income groups and trips that involve travelling with more than one transit agency. El Geneidy et al. (2016) showed how this could impact accessibility measurements in Montreal. Toronto is similar in that there are multiple transit agencies each with their own fare structure.

For the subsequent analysis, we only include people living in areas with a population density greater than 200 people/km^2. Areas under this threshold are omitted

from analysis as they typically pertain to rural or large industrial areas in our regions of study, typically areas without transit supply. Leaving these areas in our analysis would skew our results since some municipalities have more rural areas than others, depending on how the municipalities and CMAs are delineated. 200 people/km^2 is the same urban-rural threshold used by Delbosc and Currie (2011) in measuring transit equity in Melbourne, Australia, a city with similar urban form characteristics to Canadian cities.

Table 1: Summary statistics by urban region

			Transit	Mean Trip Time*		Mean Access to Jobs§	
	Population	Jobs	Mode Share†	Transit	Car	Transit	Car
Toronto	8,335,444	3,462,100	18.4%	49.2	29.0	0.09	0.38
Montreal	4,098,927	1,756,640	22.2%	44.4	26.8	0.10	0.42
Vancouver	2,745,461	1,091,405	18.7%	43.8	27.2	0.14	0.38
Calgary	1,392,609	587,280	15.9%	41.6	24.1	0.08	0.40
Ottawa	1,323,783	595,950	20.1%	42.2	24.7	0.12	0.52
Edmonton	1,321,426	553,640	11.3%	40.2	24.2	0.07	0.40
Quebec City	800,296	375,720	11.3%	35.1	21.2	0.10	0.54
Winnipeg	778,489	344,320	13.4%	35.7	22.6	0.13	0.54

† Percent of work commute trips by transit
* Mean one-way commute time for journey to work trips (in minutes)
§ Access to all jobs using equations (1-3), scaled from 0 (lowest) to 1 (highest)

4 Analyzing Inequalities in Access to Employment

In this section, we analyze the association between SES with transit access to employment using simple correlation measures. For indicators of SES, we use four income-related categories from the census; unemployment rate (UR), the log of median after-tax household income (ln MHI), and two variables of low income status tabulated by Statistics Canada, the low income measure (LIM) and the low income cut-off (LICO). The LIM is a count of households below the low-income line. This line is set at half the median household income and adjusted by the square root of the number of persons living in the household. This has the effect of raising the low income line for households with more people, but at a diminishing rate of increase (Statistics Canada, 2016a). Alternatively, the LICO pertains to households which are estimated to spend more than 20% of their income on basic necessities (e.g. food, shelter, and clothing), relative to an average family. The LICO controls for regional variations as well as household size to account for differing costs of living. These four income categories

are highly correlated. To examine their compounded effect, we also generate a combined measure of neighbourhood SES, weighting the four variables equally. This is generated as follows, where $\hat{I}$ pertains to the standardized score of each of the four measures.

$$I_{\mu} = 0.25\hat{I}_{\ln MHI} - 0.25\hat{I}_{UR} - 0.25\hat{I}_{LIM} - 0.25\hat{I}_{LICO} \quad (4)$$

The lower the I_{μ}, the lower the SES of the DA.

We then generate Pearson correlation coefficients between these income variables and transit access to jobs. We conduct this analysis in terms of access to all jobs as well as access to jobs stratified by different by income levels. Table 2 shows correlation for access to all jobs as well as access to low-income jobs. Access to all jobs and access to low-income jobs produces similar correlation coefficients with measures of SES. Similar results were also found for other income brackets, but this is not presented in the table for the sake of brevity.

Table 2: Correlation coefficients between transit access to jobs and income-related variables

	Access to all jobs					Access to low-income jobs (<$20k/year)				
	$\hat{I}_{LICO}$	$\hat{I}_{LIM}$	$\hat{I}_{UR}$	$\hat{I}_{\ln MHI}$	$\hat{I}_{\mu}$	$\hat{I}_{LICO}$	$\hat{I}_{LIM}$	$\hat{I}_{UR}$	$\hat{I}_{\ln MHI}$	$\hat{I}_{\mu}$
Toronto	0.43	0.32	0.04	-0.29	-0.32	0.41	0.33	0.05	-0.33	-0.33
Montreal	0.66	0.68	0.27	-0.48	-0.56	0.66	0.58	0.27	-0.49	-0.56
Vancouver	0.48	0.35	0.01	-0.38	-0.38	0.48	0.36	0.01	-0.40	-0.40
Calgary	0.45	0.38	-0.01	-0.36	-0.32	0.43	0.35	-0.02	-0.34	-0.29
Ottawa	0.53	0.43	0.20	-0.38	-0.44	0.52	0.42	0.20	-0.37	-0.43
Edmonton	0.58	0.46	0.09	-0.53	-0.48	0.58	0.46	0.09	-0.53	-0.48
Quebec City	0.66	0.61	0.28	-0.57	-0.62	0.66	0.61	0.28	-0.57	-0.62
Winnipeg	0.59	0.58	0.28	-0.64	-0.59	0.58	0.56	0.27	-0.63	-0.58
All	0.51	0.42	0.08	-0.37	-0.41	0.50	0.42	0.08	-0.39	-0.41

Median household income, as well as the two low-income prevalence categories (LIM and LICO), are significantly correlated with transit accessibility in each of the eight regions. This is the same overall relationship as in previous research in Toronto, which found that neighbourhoods of lower socioeconomic status tend to have better transit accessibility (Foth et al., 2013; El-Geneidy et al., 2016). Table 2 indicates that this relationship is similar, and even accentuated, in cities across the nation. Comparing between cities, we observe that transit access in Toronto and Calgary have the weakest association with income categories, while Montreal, Winnipeg, and Quebec

City have the strongest association. We also observe that unemployment is less associated with transit accessibility compared to the other income measures. Toronto, Vancouver, and Calgary do not have a strong relationship between unemployment and transit accessibility, while in the other cities, unemployed people are more likely to be in areas with good transit accessibility.

Overall, these results show that transit accessibility is vertically equitable in all of the cities included in our analysis. Transit is serving low-income residents, those who theoretically have a greater need, with higher levels of accessibility compared to high income residents. This could be due to a number of factors. One is that transit is being directly or indirectly planned to serve lower income residents. Lower-income households live in smaller units with higher levels of population density, and transit is usually more efficient in more intensely developed neighbourhoods. Second, there may be preference-selection effects. People living near transit may be satisfied with lower incomes relative to housing costs as they will not need to pay for a private vehicle, and wealthier households who have no intention to use transit choose to live in larger lots at greater distances to employment. Lower-income households without cars are more likely move to areas with higher levels of transit service (Glaeser et al., 2008). Third, there are historical factors which have led to concentrations of lower SES populations in older downtown housing stocks which have either experienced decay or were redeveloped into low-income apartment complexes in the post-war period.

5 Estimating the Extent of Transport Poverty

Despite the overall positive outlook seen in the above correlation analyses, there are still a large number of low SES neighbourhoods with low transit accessibility, and the situation of these people need to be accounted for. Also, the previous analysis correlates at a neighbourhood level, but does not take into consideration the income distributions within each areal unit. This potentially obfuscates low-income households at risk of transport poverty in neighbourhoods which have higher levels of SES on average.

To estimate the extent of transport poverty in Canada, we tabulate the number of low-income or otherwise vulnerable populations in areas of low transit accessibility. We first tabulate counts living in the lowest deciles of transit access to jobs for each region. Tabulating by deciles provides a simple interpretation like "there are X number of people living in the lowest 10% of transit accessibility for each region". However, this does not provide an adequate comparison between regions (there will always be a lowest 10%, even in a relatively high-access city). Accordingly, we also tabulate populations under certain thresholds of transit accessibility. Specifically, we count the populations in areas where transit accessibility is less than 0.1 and where it is less than 0.05 (on the scale of competitive accessibility where 0 is the minimum and

1 is the maximum observed for anyone across these eight Canadian regions). This allows for interpretation in the form of "there are X number of people living in areas of low and extremely low levels of nationally comparative transit accessibility".

These categories of low transit accessibility are cross-tabulated with four socioeconomic variables which are likely to compound with low transit accessibility and result in transport poverty. Firstly, we tabulate using two measures specified by Statistics Canada (2016), the low income cut-off (LICO) and the low income measure (LIM). These groups are more likely to face financial constraints, like not being able to afford a private vehicle, and are more likely to rely on transit. If transit accessibility is relatively low, it could increase the risk of transport poverty (Lucas, 2012). As well, we sum cross-tabulations by two other measures of socio-economic status which could compound with transport disadvantage and result in transport poverty. One is recent immigrant status (immigrated between 2011 and 2016) as recent immigrants are more likely to rely on transit due to the time-intensive process of obtaining a driving license, the cost of a vehicle, and potential language barriers (Lo, Shalaby, & Alshalalfah, 2011; Farber et al., 2018). Recent immigrants are also more likely to be in search of employment. Lastly we tabulate by the number of individuals who are unemployed, since previous research has linked difficulties of unemployed individuals in finding work with the inability to use a car and insufficient public transit options (Social Exclusion Unit, 2003; Merlin & Hu, 2017). These cross-tabulations are shown in Tables 3 and 4.

The results indicate that even though low SES residents are more likely to be in areas of higher transit accessibility, there are still a large number living in areas of low transit accessibility. These people may a be small percentage of the overall population, or even just a modest share of low-income people overall, but given the sizes of the populations under investigation, the overall number of people at risk of transport poverty is quite substantial. Calgary, Edmonton, and Toronto have particularly large counts of low-income, unemployed, and recent immigrants in areas of low transit accessibility relative to their totals, while in Quebec City, Winnipeg, and Ottawa, relatively fewer vulnerable populations are living in areas with low transit accessibility. Tabulating by deciles (Table 3) produces lower counts than by low transit accessibility (Table 4) due to how low accessibility was defined. We also looked at cross-tabs of counts by deciles of access to low-income jobs instead of access to all jobs. Percent difference between cells of the table for access to all jobs compared to low-income jobs did not exceed 8%, with a mean percent difference of only 2%. This is not presented due to similarity in results.

Table 3: Counts of all low-income residents, unemployed, and recent immigrants (2011-2016) in the lowest decile and lowest quintile of transit accessibility by region

		LIM	LICO	Unem.	Rec.Im.	Labour Force	Total Pop.
Toronto	10%	60,000	35,000	25,000	21,000	435,000	787,000
	20%	131,000	86,000	53,000	50,000	863,000	1,572,000
	Total	1,173,000	922,000	328,000	399,000	4,317,000	7,963,000
Montreal	10%	27,000	14,000	12,000	2,000	216,000	380,000
	20%	51,000	29,000	23,000	6,000	420,000	746,000
	Total	598,000	472,000	158,000	178,000	2,092,000	3,925,000
Vancouver	10%	27,000	20,000	7,000	7,000	145,000	273,000
	20%	54,000	40,000	15,000	16,000	287,000	537,000
	Total	422,000	349,000	86,000	148,000	1,440,000	2,637,000
Calgary	10%	8,000	5,000	7,000	7,000	80,000	138,000
	20%	15,000	11,000	14,000	17,000	158,000	269,000
	Total	118,000	108,000	74,000	92,000	789,000	1,343,000
Ottawa	10%	8,000	4,000	3,000	1,000	64,360	117,479
	20%	15,000	9,000	7,000	3,000	128,000	229,000
	Total	148,000	125,000	46,000	37,000	639,000	1,169,000
Edmonton	10%	7,000	4,000	6,000	3,000	73,000	128,000
	20%	13,000	8,000	11,000	8,000	134,000	242,000
	Total	112,000	99,000	59,000	77,000	692,000	1,203,000
Quebec City	10%	4,000	2,000	1,000	500	40,000	70,000
	20%	6,000	4,000	3,000	500	78,000	135,000
	Total	75,000	62,000	18,000	13,000	388,000	712,000
Winnipeg	10%	6,000	5,000	2,000	4,000	39,000	69,000
	20%	10,000	8,000	4,000	7,000	77,000	136,000
	Total	109,000	91,000	25,000	52,000	387,000	712,000
All	10%	147,000	89,000	64,000	45,000	1,092,000	1,963,000
	20%	296,000	197,000	129,000	107,000	2,151,000	3,866,000
	Total	2,755,000	2,228,000	794,000	996,000	10,744,000	19,663,000

Table 4: Counts of all low-income residents, unemployed, and recent immigrants (2011-2016) in areas of low (<0.1) and extremely low (<0.05) transit accessibility

	$A_{i,T}$	LIM	LICO	Unem	Rec.Imm.	Labour Force	Total Pop.
Toronto	<0.05	330,000	234,000	129,000	121,000	1,856,000	3,406,000
	<0.1	638,000	472,000	212,000	225,000	2,867,000	5,330,000
	Total	1,173,000	922,000	328,000	399,000	4,317,000	7,963,000
Montreal	<0.05	136,000	87,000	53,000	23,000	913,000	1,658,000
	<0.1	242,000	168,000	82,000	55,000	1,274,000	2,374,000
	Total	598,000	472,000	158,000	178,000	2,092,000	3,925,000
Vancouver	<0.05	115,000	86,000	30,000	39,000	534,000	1,014,000
	<0.1	199,000	152,000	47,000	72,000	798,000	1,510,000
	Total	422,000	349,000	86,000	148,000	1,440,000	2,637,000
Calgary	<0.05	39,000	33,000	32,000	40,000	354,000	609,000
	<0.1	74,000	66,000	53,000	66,000	564,000	979,000
	Total	118,000	108,000	74,000	92,000	789,000	1,343,000
Ottawa	<0.05	18,000	11,000	9,000	4,000	154,000	274,000
	<0.1	45,000	32,000	20,000	13,000	341,000	613,000
	Total	148,000	125,000	46,000	37,000	639,000	1,169,000
Edmonton	<0.05	38,000	30,000	28,000	32,000	356,000	614,000
	<0.1	69,000	58,000	43,000	53,000	523,000	916,000
	Total	112,000	99,000	59,000	77,000	692,000	1,203,000
Quebec City	<0.05	10,000	6,000	4,000	1,000	119,000	206,000
	<0.1	24,000	17,000	9,000	3,000	228,000	405,000
	Total	75,000	62,000	18,000	13,000	388,000	712,000
Winnipeg	<0.05	7,000	6,000	2,000	4,000	46,000	82,000
	<0.1	25,000	20,000	8,000	15,000	155,000	279,000
	Total	109,000	91,000	25,000	52,000	387,000	712,000
All	<0.05	692,000	492,000	287,000	265,000	4,338,000	7,864,000
	<0.1	1,315,000	985,000	475,000	502,000	6,749,000	12,406,000
	Total	2,755,000	2,228,000	794,000	996,000	10,744,000	19,663,000

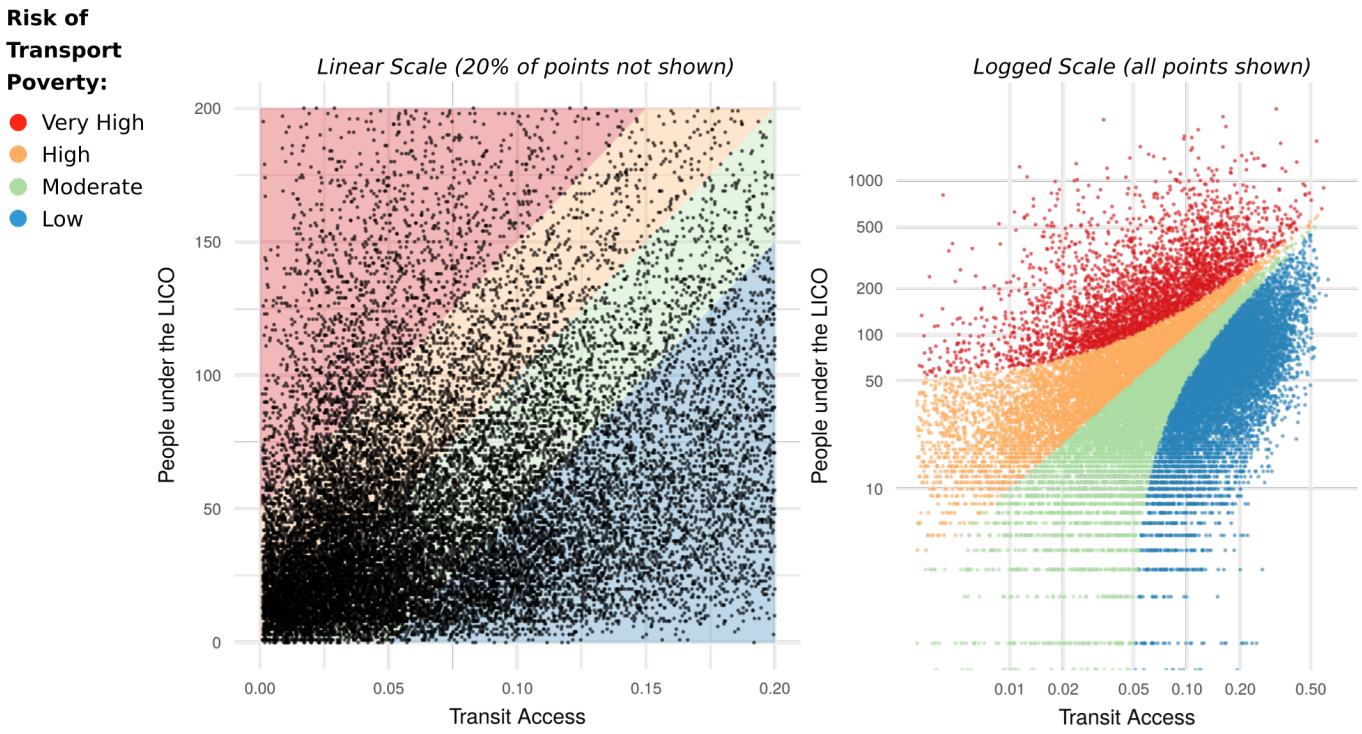
6 Creating a Typology of Transport Poor Neighbourhoods in Canada

We now analyze the characteristics of areas that are at risk of transport poverty in order to support discussion and policy recommendations. We first classify Dissemination Areas (DA) in terms of their risk of experiencing transport poverty. Theoretically, transport poverty is more likely to occur where there is low transit accessibility and lower levels of SES. For the scope of this paper, we simplify to assume that areas at risk of transport poverty are those with low transit access to employment, and have high counts of people living under the regionally adjusted low-income cut-off (LICO). We use the compounding effect of these two variables to classify DAs into four categories of risk of transport poverty (low, moderate, high, and very high). The classification was based on the assumption that both transit accessibility and prevalence of low-income residents contribute linearly to the risk of transport poverty. This relationship is visualized Figure 1 in a linear plot and log-log plot. Overall, 12% of DAs are classified as very high risk and 23% as high risk of transport poverty. Toronto and Vancouver have the greatest percent of their DAs at high risk of transport poverty, and the smaller cities of Winnipeg and Quebec have the lowest (see Table 5). Toronto and Vancouver are also the two cities which have been reported on the most in terms of experiencing rising housing costs and sub-urbanization of poverty (Ades et al., 2012, 2016).

Table 5: Percent of DAs classified by risk of experiencing transport poverty in each region

	Low	Moderate	High	Very High
Toronto	30.0%	31.0%	24.0%	15.1%
Montreal	30.5%	32.1%	26.9%	10.5%
Vancouver	35.9%	20.7%	27.7%	15.8%
Calgary	35.6%	34.3%	19.9%	10.2%
Ottawa	53.6%	24.2%	13.5%	8.7%
Edmonton	29.9%	35.0%	24.0%	11.1%
Quebec City	49.6%	34.4%	13.8%	2.1%
Winnipeg	62.4%	22.0%	8.9%	6.7%
All	34.8%	29.6%	23.2%	12.4%

Figure 1: Classifying DAs in terms of risk of experiencing transport poverty (each dot in the plots represents a DA)



Lastly, we conduct a k-means cluster analysis of zones at risk of transport poverty in order to generate a typology that can be used for policy recommendations. Specifically we cluster on DAs that we classified as high or very high risk of transport poverty. We cluster these DAs using seven relevant variables; access to jobs by transit, access to jobs by car, population density, percent of population living in apartments, number of residents in low-income households, percent of residents living in new housing stock (built since 2000), and the percent who have moved recently (from 2011 to 2016). The resulting number of clusters ($k = 2$) was determined by generating a Scree plot, and then selecting the k where the graph provides the greatest change in slope. The means of the variables selected in the cluster analysis for the two resulting groups are displayed in Table 6. Table 6 also shows the number of DAs in each category, and the number of DAs that were previously categorized as being high or very high risk of transport poverty. There is a greater proportion of DAs that have a very high risk of transport poverty in the first group, which also has greater population density and high percent of people living in apartments.

Table 6: Cluster analysis results of DAs at risk of transport poverty

mean	Group A	Group B
Auto Access	0.481	0.235
Transit Access	0.117	0.032
Population Density (ppl/km2)	8,281	3,287
People under the LICO	257	74
Percent living in apartments	74%	14%
Percent moved 2011-2016	51.8%	36.3%
Percent in dwellings built since 2000	16.3%	26.3%
n DAs	2,252	7,239
n Very high risk of transport poverty	1,388	1,750
n High risk of transport poverty	864	5,489

We can summarize by saying that there are two main typologies of areas in which people are at a high risk of experiencing transport poverty. One are areas with high population density, primarily people living in older apartments, with very high concentrations of low income residents, who were more likely to have moved recently, and who have average levels of transit access to employment (Group A). The second (Group B) are more peripheral, typical suburban single family housing, low density neighbourhoods, with extremely low levels of transit accessibility, have a wider gap between the relative level of transit accessibility to auto accessibility, more likely to be living in newer housing stock, but have fewer low income residents. Put simply, transport poverty is most apparent in very dense, low-income, tower-neighbourhoods located off of the main axes of transit supply, or wherever low income populations live in low-density suburban urban forms across the nation.

7 Policy Recommendations

Our research shows that while there are not systemic vertical inequalities in transit accessibility, there are still a substantial number of low-income Canadians living in areas of low transit accessibility. We estimate that 40% of all low-income residents in these cities are at risk of transport poverty, 5% of the overall population, and nearly one million people in total. The literature explains that the compounding effects of low transit accessibility and low SES increase the risks of transport poverty, potentially limiting people in their ability to travel to and participate in daily activities, including finding and retaining employment (Preston & Rajé, 2007; Paez et al., 2009; Lucas, 2012). Investing in public transport to improve accessibility, particu-

larly focused towards those at risk of transport poverty, has the potential to reduce inequalities, limit barriers to activity participation, and foster social and economic inclusion.

This leads to the broad conclusion that transport policy in Canadian cities should focus towards improving transit service to low accessibility neighbourhoods, with particular focus towards those neighbourhoods with more low-income households since they are more likely to be reliant on transit. Unfortunately, there is only a limited amount of funds and resources available for improving public transportation in Canadian cities. Certainly, this points towards advocating for increasing public funding for public transit service, either through raising taxes (e.g. like gas taxes or congestion charges) or re-allocation of government spending from other infrastructure (e.g. shift spending from highways to transit). However, it would be quixotic to think that there will be a sufficient amount of funds for desirable levels of public transit provision in urban areas across Canada in the near future. The prevailing challenge of urban transportation planning is deciding how to allocate scarce funds and resources to where they are to be the most effective.

The previous section indicates that there are two types of areas at risk of transport poverty. The first group have high levels of population density (e.g in apartment towers) and high concentration of low income residents. These are usually located in the "inner-suburbs" of urban areas, and typically already have some transit service in place, but the existing service is low relative to the socioeconomic status and density of residents. Due to greater density, improving transit accessibility in these areas would be the most effective in reducing risks of transport poverty for a large group of people. Indeed, those areas with particularly high concentrations would be ideal candidates for new rapid or regional transit stations. However, this would only be realistic solution in a few locations given the high capital costs of such infrastructure. For most areas, more cost effective solutions should be considered for upgrading existing service. One would be increased frequency on existing bus routes by adding more vehicles to limit wait times, particularly for routes with large headways. Travel times could also be reduced by implementing express lines which make fewer intermittent stops. Another cost-effective solution would be to alter the design of roads to incorporate dedicated bus lanes (i.e. BRT), to depose delay caused by auto congestion. The majority of suburban arterial roads in Canada have ample room to implement dedicated bus lanes, a convenience of the unbridled auto-oriented planning of the previous decades. Planning new routes, or upgrading existing routes, should not be offset by reducing or re-routing other existing bus routes relied upon by lower-income residents, which has unfortunately been the case in American cities like Los Angeles (Grengs, 2002) and Salt Lake City (Farber & Fu, 2017).

Improving transit accessibility in lower density, single-family housing areas is a greater challenge given the greater dispersement of individuals. In these regions, many transit agencies opt for coverage rather than directness in their design of suburban

transit routes. It may be possible that faster, more direct, routes in some instances will have a greater potential in providing greater accessibility, depending on the spatial distribution of transit need in the region (Walker, 2012). Transit networks should also focus on providing better links to suburban employment locations. Many suburban employment areas currently have sparse transit service, despite recent growth in employment numbers and suburb-to-suburb commuting (Blais, 2015).

Another potential solution, or as an augmentation to other solutions, is to provide subsidies for ride-sharing or implement demand responsive transit services. This could be beneficial in lower-density suburban areas, where implementing traditional fixed-route transit service has substantial monetary costs, or in areas where there is a last mile problem. A few regions have begun to experiment with this type of service. For example, the growing town of Innisfil (north of Toronto), recently partnered with Uber to subsidize an on-demand ride-sharing service, as a more economical alternative to developing traditional, fixed-route, transit service (Town of Innisfil, 2017). While this may be a solution for alleviating transport poverty in areas with less demand, it may not be applicable in urban areas where there is already heavy congestion or a greater need for adding higher capacity transit (Mageean & Nelson, 2003). Evaluating the success of such projects however will provide useful knowledge on how and where demand responsive transit could be implemented elsewhere in Canada, and whether it can be appropriately scaled if demand for transit increases.

In conjunction to the aforementioned recommendations for transit improvement, municipalities and regional planners should also enforce land use policies which restrict urban sprawl and zone for urban intensification and mixed-use development, in order to help reduce commute times and auto-dependency. This should include planning any future development of housing for low-income residents and recent immigrants to be in areas with high transit accessibility. This should also include focusing some employment growth in areas which have existing transit service, but have low accessibility metrics due to a local absence of jobs - areas where there are an abundance of labourers who currently have to travel further to find employment. These ideas of "smart growth" and denser, transit-oriented development, are often cited by urban planners to reduce congestion and environmental impacts (Bernick & Cervero, 1997). This sphere of development strategies can also reduce risks of transport poverty by providing more nearby opportunities.

Lastly, it is possible that in the long term, providing better transit accessibility to a neighbourhood could increase demand and costs for housing. This would likely first affect low-income people in these areas for whom transit is the only option for daily travel. Rising costs could then result in displacement to less accessible areas. This indicates the importance of policy directed towards maintaining stability and affordability of housing costs, in order to break any cycles of displacement. This also shows the importance of ensuring minimum standards of accessibility across an entire region, given uncertainties of housing markets and living costs in the future.

8 Conclusion

In this study, we examined inequalities in transit access to employment for eight Canadian metropolitan regions. We find that neighbourhoods of lower SES, on average, have higher levels of transit access to employment than the overall population. These trends are similar across all eight cities, but are less apparent in the larger cities of Toronto and Vancouver, which have faced more gentrification and dispersion of poorer populations into suburban areas. Despite an overall positive outlook, there are still many households at risk of experiencing transport poverty. We estimate that there are nearly one million urban Canadians living in low-income households who are also living in areas of low transit accessibility. This accounts to 5% of the population in these regions.

Recommendations to reduce inequalities in transit accessibility and limit risks of transport poverty include focusing future transit investments in areas which have high concentrations of low-income households and low levels of transit accessibility, upgrading bus levels of service, intensification and diversity of land-use to increase accessibility and reduce commute distances, as well as a consideration of subsidizing ride-sharing or implementing demand-responsive transit in areas of low density. Doing so could help reduce the risks of transport poverty and social exclusion. Given recent and likely continuing growth of poverty in the suburbs, it is imperative that these regions have adequate transit service, not only to find employment opportunities, but to participate in other daily activities constituting a high quality of life.

This study used access to employment as a proxy measure for the distribution of transit benefits across multiple regions. We do not contend that this research shows a direct link between transport investments and employment outcomes, as this is dependent on many other factors such as education, social networks, skill development, and other services aimed at reducing barriers to employment. Future research that explores the impacts of jobs accessibility on employment outcomes could adopt the accessibility measures in this study, but should additionally focus on matching the skills of unemployed jobs seekers with available job openings during accessibility calculations, rather than analyzing the locations of the overall labour force and employment. However, from our knowledge, comprehensive data for job seekers and job openings does not exist Canada-wide. This highlights that the Canadian transport policy sector needs to advocate to make detailed employment data available to researchers in order to advance analysis beyond existing studies which rely on aggregate census data. If available, this additional information, along with greater consideration for travel costs and reduced willingness to travel for lower SES households, would provide a deeper understanding of the who and where of transport poverty in Canada, and be more effective at aiding policy aimed at poverty reduction.

While applied to Canadian cities, this paper adds to the literature by detailing

a methodology for accounting for transport poverty. From our knowledge, a large-scale, multi-city accounting of transport poverty has not been conducted anywhere in the world. We also outlined a novel method for generating descriptive typologies of transport poor neighbourhoods that can directly inform policy recommendations. The methods detailed on accounting for transport poverty and describing transport poor neighbourhoods could be similarly be applied elsewhere. This is highly relevant as concern regarding transport poverty is escalating in regions around the world. Moreover, the policy discussion provided in our paper is applicable to other regions, particularly for urban areas in the United States, Australia, and Europe which have similar transport and land use patterns as Canadian cities.

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