Affordable and fair?
Analyzing transit fare purchases, service quality, and affordability and their implications for social equity

A supervised research project by
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Submitted to
School of Urban Planning
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Supervised Research Project Report

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"Every city that acts like a city has transit."

—Frederick P. Salvucci

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ABSTRACT

Public transport agencies have the difficult task of providing service that meets the desires and needs of the residents of a city while remaining financially viable. Unfortunately, in North America, funding cutbacks often precipitate either service adjustments or fare increases, or often both. As a result, transit may become a less attractive for choice riders, but may become altogether unaffordable and inconvenient for captive riders who are typically marginalized members of society and have no choice but to rely on public transport for travel. In this research project, I investigate how median income of a neighbourhood influences transit fare purchases, as well as the affordability and service quality supplied by transit agencies in the fourteen largest North American cities.

First, I studied whether the type of transit fare purchased, either a monthly fare or a weekly fare, depends on income. I discovered that in Montreal, lower incomes increase the purchase of multiple weekly fares. This finding suggests that individuals residing in low-income neighbourhoods may purchase weekly fares as a substitute for monthly fares since monthly fares require greater upfront costs. Moreover, tied to the idea of transit affordability is whether a transit agency can supply quality service at an affordable price. To investigate this issue, I used publicly-available data to assess the performance of transit agencies based on a parsimonious set of indicators aimed at capturing the perspective of transit riders, society as a whole, and transit agencies themselves. Overall, transit agencies with the best quality are relatively expensive for minimum wage earners, and worse still, some agencies provide poor quality service that is also expensive. Nevertheless, the SFMTA in San Francisco and the STM in Montreal are two agencies that are the most affordable that also provide good service to their riders.

My findings indicate that low-income riders may be overburdened by transit fares and call for reduced fares for low-income earners or the adoption of a new fare policy, such a fare capping. Moreover, my research suggests that North American transit agencies have difficulty providing quality service that is also affordable for minimum wage earners. Taken together, my research adds to the growing body of evidence demonstrating the difficulty that disadvantaged residents face when

financially accessing public transport. From a social equity perspective, in order to provide financially viable transit service that meets the needs of all, transit fares should be harmonized with the ability pay.

RÉSUMÉ

Les agences métropolitaines de transport ont un mandat difficile de fournir un service qui répond aux désirs et aux besoins des résidents, tout en restant financièrement viables. Malheureusement, les agences se voient souvent dans l'obligation de réduire leur service ou d'augmenter leur prix en raison de coupures dans le financement du transport en commun. Ces changements peuvent rendre le service moins attirant pour l'ensemble des usagers. De plus, le transport en commun peut devenir non abordable pour les usagers vulnérables qui dépendent du transport en commun pour leurs déplacements quotidiens. L'objectif de cette recherche est donc d'explorer dans quelle mesure le revenu médian d'un quartier influence l'achat de billets de transport en commun, et d'analyser la qualité, et l'accessibilité financière, du service fournie par les agences de transport en commun dans les 14 plus grands villes américaines.

En premier lieu, j'ai étudié si le type de billet acheté (mensuel ou hebdomadaire) était influencé par le revenu. Les résultats indiquent que, à Montréal, un revenu plus faible augmente l'achat de passes hebdomadaires multiples, comparativement à l'achat d'une passe mensuelle. Ces résultats suggèrent que les individus résidant dans des quartiers dont le revenu médian est plus faible pourraient acheter de multiples passes hebdomadaires en remplacement d'une passe mensuelle, étant donné qu'une passe mensuelle requiert un plus grand débours au début du mois. De plus, une autre question liée à l'accessibilité financière réside dans la capacité des agences à fournir un service de qualité, à un prix abordable. Pour explorer cet enjeu, j'ai utilisé des données publiques me permettant d'analyser la performance des agences de transport, en fonction d'une série d'indicateurs visant à cerner la perspective des usagers, de l'ensemble de la société, et des agences de transport. De façon générale, les agences de transport fournissant les services de plus haute qualité s'avèrent relativement dispendieuses pour les individus à salaire minimum. Par ailleurs, certaines agences fournissant un service de faible qualité sont elles aussi dispendieuses. Néanmoins, la SFMTA à San Francisco et la STM à Montréal sont les deux agences les plus abordables qui fournissent aussi un bon service à leurs usagers.

Les résultats de ma recherche indiquent que les usagers à faible revenu peuvent porter un fardeau important en termes de coût du transport et mettent en perspective la nécessité d'implanter des tarifs réduits pour les individus à faible revenu, ou l'adoption d'une nouvelle politique tarifaire, telle qu'un plafond tarifaire. De plus, les résultats suggèrent que les agences de transport nord-américaines ont de la difficulté à fournir un service de qualité qui soit abordable pour les moins nantis.

Dans l'ensemble, ma recherche s'ajoute aux preuves grandissantes démontrant les difficultés auxquelles font face les résidents vulnérables en matière d'accessibilité financière. Dans une perspective d'équité sociale, les tarifs de transport en commun devraient être harmonisés avec la capacité de payer de chacun des usagers, afin de fournir un système de transport en commun financièrement viable qui rencontre les besoins de tous les résidents d'une région urbaine.

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CHAPTER 1. INTRODUCTION

Public transit is increasing in popularity and use. For example, last October saw the most trips taken on the New York City subway for a weekday since the 1940s (MTA, 2015). Indeed, after reaching a nadir during the 1970s and 1980s, reinvestments in public transit in the United States and Canada in the 1990s have helped grow ridership (Seaman, de Cerreno, & English-Young, 2004). The desire to increase public transit use is consistent with the focus of making cities more sustainable and liveable.

Who in a city has access to public transit is an important concern, particularly since transportation projects are mainly paid for with public funds (Manaugh & El-Geneidy, 2012; Martens, Golub, & Robinson, 2012). As such, an equitable distribution of transportation infrastructure and the benefits accrued from this infrastructure are goals in many city and transport agency planning documents, although concretizing these goals is difficult and sometimes elusive (Manaugh, Badami, & El-Geneidy, 2015). Contemporary research in social equity and public transit tends to focus on accessibility and whether disadvantaged populations are able to access desired destinations, such as jobs and social opportunities (Delbosc & Currie, 2011; Foth, Manaugh, & El-Geneidy, 2013; Geurs & van Wee, 2004; Litman, 2002). In addition to physically accessing transit, city residents must also be able to financially afford public transit.

Transit fares may pose a barrier to some people, particularly low-income people, such as single parents, elderly people on a pension, and students (Taylor & Norton, 2009). While discounted transit fares are typically offered to students and the elderly, fewer transit agencies offer discounts for low-income populations (Taylor & Jones, 2012). Furthermore, transit agencies attempt to achieve financial solvency which typically depends on transit fares, while providing an acceptable level of service at an affordable price (Badami & Haider, 2007). While transit agencies can raise fares to cover revenue generation related to investments or capital programs (Aggarwala, 2012), in the United States, proposed fare increases must undergo scrutiny to ensure compliance with civil rights legislation, essentially safeguarding minority and low-income groups from burdensome transit fares (Grengs, 2002; METRO, 2016).

The overarching theme of this research project is the financial affordability of public transit. In particular, this work was inspired by a finding that entries into New York City subway stations located in many low-income census tracts are predominant based on the use of weekly passes, while entries in high-income census tracts are mostly from monthly passes (Hickey, Lu, & Reddy, 2010). This observation is germane given that weekly passes, while cheaper to purchase upfront, cost more if purchased repeatedly over the course of a month as a substitute for a monthly pass—buying in bulk is cheaper (Schuerman, 2015). In particular, low-income earners may be unable to put down the large sum required for a monthly pass and opt instead to purchase weekly passes (Provost, 2015; Schuerman, 2015). Since they end paying more over the long-term than their high-income counterparts, this situation overburdens already vulnerable people. Therefore, in Chapter 2 of this project, I investigated how transit fare purchases on the Island of Montreal may be influenced by median income. I found that at the neighbourhood level, lower incomes predict greater multiple weekly fare purchases than in neighbourhoods with higher incomes. These results suggest that in Montreal, residents of marginalized neighbourhoods may purchase weekly fares as substitutes for monthly fares, and as a result, spend more money than residents in wealthier neighbourhoods on transit passes.

In response to these findings, a spokesperson from the Montreal transit corporation countered that among North American agencies, Montreal has some of the most affordable fares (Provost, 2015). This prompted a number of questions: If Montreal's transit is considered affordable, does the transit agency provide good quality service? If other agencies have more expensive fares, do they provide better service? Are there agencies that provide as good or better service more affordably? And even if the cost of fares is lower in Montreal than in other cities, how affordable is it for minimum wage earners compared to other cities? To begin answering some of these questions, in Chapter 3, I present a critical analysis of the affordability and the quality of service offered by transit agencies in large North American cities. Using publicly-reported transit data, I created indicators based on features desired by transit riders: accessibility to jobs, service frequency, and comfort. Using the hourly minimum wage, I also calculated the number of hours needed to purchase a monthly transit fare as a measure of affordability for low-income users and compared the different quality indicators with affordability. In addition, I also considered the perspective of financial viability of transit agencies and the benefits provided by public transport to society by having a system that is well-used. Overall, by combining different perspectives, I discovered that the best performing agencies are typically expensive for minimum wage earners, except for transit in Montreal and San Francisco, where their respective transit agencies seem to provide quality and affordable service. With this methodology, I provide a framework for researchers and practitioners wishing to assess and compare the quality and affordability of public transport systems.

CHAPTER 2. PUBLIC TRANSIT FARE STRUCTURE AND INCOME VULNERABILITY IN MONTREAL, CANADA[1]

2.1 INTRODUCTION

A public transit network capable of moving many residents to diverse locations is an integral characteristic of any city. A large focus of public transit research deals with scheduling and operations or travel behavior and mode share, but fewer studies have investigated fare structures and purchasing. Moreover, from a social equity perspective, a growing body of literature has asked whether transit benefits and projects are distributed equitably in a region (Delbosc & Currie, 2011; Foth et al., 2013; Manaugh et al., 2015; Martens, 2012), but few studies have addressed the equity impacts of fare structures. In fact, transit fares may form an important barrier for the working poor (Stolper & Rankin, 2016). One recent example of research on fare structures was a study in New York City, where researchers discovered that entries at subway stations in low-income census tracts were predominately from seven-day fare cards, while entries at stations in higher income census tracts were largely from monthly fare cards (Hickey et al., 2010). In New York City—as in many other cities—purchasing multiple weekly fares as a substitute for a monthly fare costs more in the long run since buying in bulk is cheaper. However, low-income earners may be unable to spend a large amount at one time for a monthly fare, opting instead to buy weekly fares that are cheaper in the short-term but costlier in the long-term (Schuerman, 2015; Stolper & Rankin, 2016).

In this paper, we investigate how purchases of different transit fare types may relate to income, with implications for social equity. We studied purchases of transit fares using OPUS card transaction records, the transit fare smartcard of the transit agency of the Island of Montreal, Canada, the Société de transport de Montréal (STM) (STM, 2015a). To shed light on the spatial and socioeconomic factors that underlie different types of fare purchases, we model the number of total monthly fares purchased,

[1] This chapter is currently under review as a manuscript at *Transportation Research Part A: Policy and Practice*.

total weekly fares purchased, and the number of riders who purchased three or more weekly fares during September 2014. We hypothesize that some low-income earners may be unable to purchase monthly passes because of the high upfront cost, and buy weekly passes as a substitute; while a weekly pass is less expensive upfront, buying three or more weekly passes over the course of the month is costlier (per ride). Based on our hypothesis, we expect to find concentrations of weekly fare transactions predominately in low-income neighbourhoods, and we also predict that income will be a significant explanatory variable of three or more weekly fare sales that we hereafter refer to interchangeably as recurring, repeated, or multiple weekly fare sales.

The paper begins with a review of the relevant literature on transport equity and transit fares. Next, we provide background on the Montreal context and transit fare structure of the STM, Montreal's main transit provider. Third, we describe our dataset, methods, and modelling approach. Fourth, we explain our models and findings. Lastly, we discuss our findings and potential policy relevance.

2.2 LITERATURE REVIEW

An emerging body of literature has brought social equity concerns to the forefront of many disciplines, including land use and transportation planning (Geurs, Boon, & Van Wee, 2009; Martens, 2012). Nevertheless, in many instances, what equity entails is murky including equity in transportation planning (Manaugh et al., 2015) and the definition of equity itself (Taylor & Norton, 2009). Generally, equity in reference to planning, as espoused by Krumholz and Forester (1990), means allocating more resources to those who have the least. This idea would propose ensuring that socially vulnerable populations, who are typically bounded to transit (APTA, 2007), have a larger share of transportation-related benefits, such as accessibility to jobs by transit (Foth et al., 2013) or access to transit itself (Delbosc & Currie, 2011; Welch, 2013), than individuals with more transport options, like a private vehicle. With regard to transit fares, an equitable scheme consistent with Krumholz and Forester's (1990) thesis would be one where low-income individuals pay less, while individuals who can afford to pay more will pay a larger fare (Aggarwala, 2012).

Many different fare schemes are used by transit agencies with varying impacts on social equity. In North American cities, many transit agencies charge flat fares for city bus and subway services (Cervero, 1981), regardless of distance travelled or mode. Since low-income residents tend to live in central city neighbourhoods well-served by transit (Glaeser, Kahn, & Rappaport, 2008), these residents likely travel shorter distances and thus are poorly served by flat fares. On the other hand, commuter rail tends to be zonal in fare structure and is mostly used by affluent white-collar workers (Taylor & Morris, 2015). These schemes also apply to Montreal, where one flat fare is used for city buses and metros, but commuter rail fares are zonal. Recent work using spatial modelling to examine a switch from flat to distance-based fares found that this switch is advantageous for minority and low-income riders in Wasatch Front, Utah (Farber, Bartholomew, Li, Páez, & Nurul Habib, 2014). In addition to considering fares based on distance or time of day, different fares types, such as monthly unlimited or weekly unlimited passes are also used by many agencies. The price-per-ride of a monthly pass is usually less expensive than weekly or daily single fares.

With varying fare schemes, demand for transit can be managed. For example, longer trips in Beijing are most affected by fare increases (Wang, Li, & Chen, 2015), while in New York City, estimated ridership loss is less for increases in unlimited monthly fares compared to weekly fare increases (Hickey, 2005), implying that sensitivity of ridership depends on fare structure and type. By evaluating several scenarios of Alameda-Contra Costa Transit, California, Nuworsoo, Golub, and Deakin (2009) found that vulnerable riders, including low-income riders, youth, and minorities would be penalized more by scenarios that would increase flat fares per ride due to more transfers and more trips compared to affluent riders who could afford to purchase a monthly pass. In contrast to agencies with flat fares or costlier fares for fewer rides, in Washington, D.C., distance and peak trips determine transit fares, and per ride, weekly fares cost the same as monthly fares (WMATA, 2015). Washington’s approach to charging lower fares during off-peak hours could address some equity concerns (El-Geneidy et al., 2015; Taylor & Norton, 2009). To specifically address vulnerable populations who depend on transit,

transit agencies in San Francisco, Seattle, and Calgary, for example, have programs for subsidized transit passes for low-income riders (SFMTA, n.d.; King County Transit, 2015; Calgary Transit, 2015).

Nevertheless, few studies have considered the factors underlying transit fare purchases. By estimating travel demand in Athens, Greece, researchers uncovered that the fare type can influence ridership, and this varies by mode as well as fare price (Gkritza, Karlaftis, & Mannering, 2011). While that study used some sociodemographic indicators, namely income and immigrant status, to determine their association with fare purchases, detailed demographics were lacking. This is likely due to the inability to link riders and demographics directly. Given the scarce research on income and transit fare purchasing with implications for social equity, a closer examination of how income can influence transit fare purchases is warranted.

2.3 DATA AND METHODOLOGY

2.3.1 Montreal background and context

Montreal is the second largest metropolitan region in Canada, at roughly 4 million inhabitants, and is located in the south of the province of Quebec. The City of Montreal, along with on-island municipalities, is located on Montreal Island in the Saint Lawrence River, and is served by the STM, the local transit agency operating the metro and buses on the Island. The regional transit authority runs suburban trains that feed central intermodal stations in downtown Montreal.

Launched in 2008–2009, the OPUS smartcard fare system is used by transit agencies throughout the Greater Montreal region (STM, 2015a). OPUS card users purchase a card ($6.00 CAD) and then load fares onto the card at metro and train stations, as well as authorized vendors throughout the region. In our study, we focused on transactions from vendors and stations located only on the Island of Montreal and its associated islands (including Île-Bizard and Île-des-Soeurs) (Fig. 2.1), the STM’s major service area.

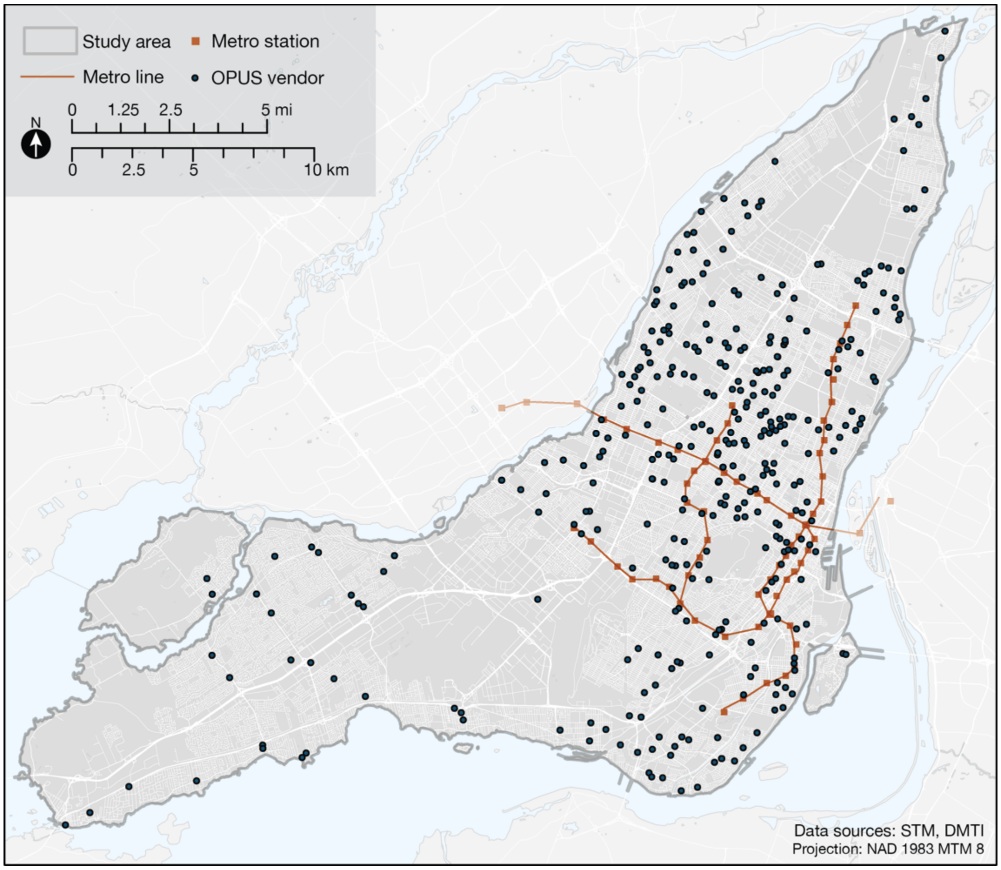

Figure 2.1. Context map of the Island of Montreal.

In 2014, a single fare cost $3.00, while a two-way trip fare cost $5.50. Weekly fares (valid from Monday 5 a.m. to Sunday 11:59 p.m.) cost $24.50, and monthly fares (valid from the first day to the last day of the month) cost $79.50, so buying weekly passes (four) for an entire month is costlier overall than purchasing a monthly pass. Moreover, when buying three weekly passes in a month, spending $6.00 more, or the equivalent cost of two single trips, would have enabled unlimited monthly access; buying a monthly pass instead of three weekly passes is more worthwhile. While reduced cost senior and student fare cards are personalized with photo IDs, regular OPUS cards are not personalized.

While we initially wished to study a larger time frame of purchases (six months), the time requirements to extract transaction data are significant, and thus we limited our data request to a single month. To our knowledge, no special events occurred in September 2014 that would have significantly affected fare sales, and we chose September to limit the number of potential tourist sales during summer months or weekly sales because of residents' holidays during the summer.

2.3.2 Data preparation

A total of 1,010,720 fare purchases were completed within the month of September 2014. These transactions originated from 602,609 unique OPUS cards and took place both at transit stations (70 locations/Metro or transit stations) and points of sales such as corner stores and pharmacies (363 vendors). Note that these transactions include all cards that made purchases, ranging from single fares, to monthly fares, to suburban train fares, as well as multiple purchases. Moreover, these transactions included both regular and reduced fare purchases, which include purchases made by students under 18 years old, students between 18–25 years old, and seniors over 65 years old. For this study, only regular fares are examined because reduced fares cannot be stratified into different groups (students vs. seniors) due to the similarity in price. For the five calendar weeks in September 2014, 63,262 regular weekly passes were sold at transit stations and 34,707 were sold at local vendors. In terms of monthly passes (both for September and October pass, since monthly passes are available on the 20th day of the preceding month), 145,970 were sold at transit stations while 57,762 were sold at local vendors.

For data preparation (Fig. 2.2), fare purchases originating from metro stations off the Island of Montreal were removed because off-island residents need to buy fares for their regions (and were not recorded in our dataset) as well as fares to access the STM system (present in our dataset). Also records from the main passenger airport were removed because of the non-residential nature of the surrounding area and potential skewing due to tourist purchases. Any records that contained more than one purchase of the same fare type (e.g., two of the same week or two of the same month) were also removed as errors. In all, transactions taking place at a total of 407 different points of sale (interchangeably referred to as 'locations' including 64 transit stations and 343 local vendors) are analyzed in this study. The final analyses included 61,959 weekly fares from transit stations (2% removed) and 32,892 weekly fares from vendors (5% removed). For monthly fare transactions, 144,688 fares were analyzed from transit stations (<1% removed) and 53,394 monthly fares from vendors (7%

removed). To analyze recurring purchases of weekly fares (three or more weekly fare purchases during the month), individual OPUS IDs were extracted and only IDs that made repeated purchases at a single point of sale (i.e., excluding IDs that bought multiple weekly passes at different locations) were examined. We also excluded IDs that purchased repeated weekly fares as well as monthly fares. This subset contained 5,395 unique purchasers of three or more weekly fares at a unique location in the month of September 2014.

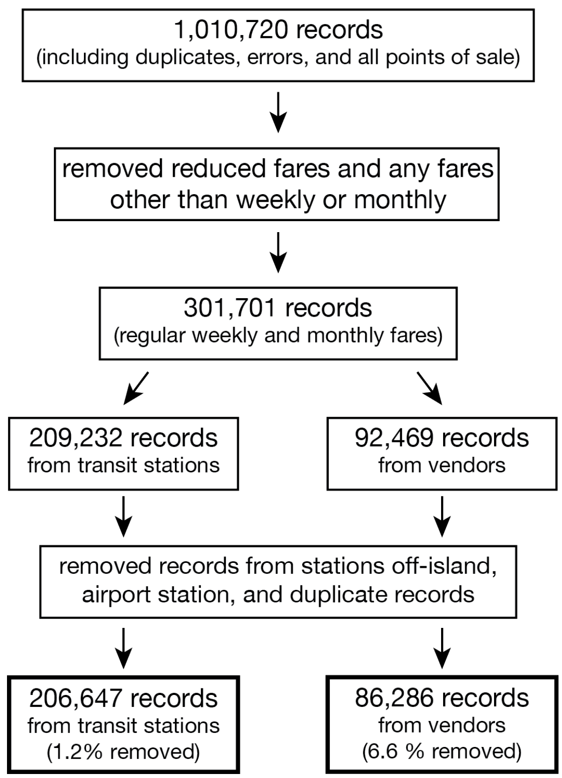

Figure 2.2. Data preparation.

The dependent variables (see Table 2.1) are the total number of monthly fares purchased at a location, the total number of weekly fares purchased at a location, and the number of purchasers of three or more weekly fares from a unique location. When testing for normality with Shapiro-Wilks, Shapiro-Francia and skewness tests, as well as visually analyzing a frequency plot of dependent variables, we determined that the dependent variables were not normally distributed. Therefore, the monthly fare dependent variable was transformed as a natural logarithm. Moreover, since five vendors had no weekly sales and 52 vendors had no three or more weekly sales, we used a multilevel Poisson regression model to account for vendors with dependent variables equal to 0, as well as the non-normality of the dependent variables.

2.3.3 Income and spatial variables

To link neighbourhood characteristics to each vendor, we generated a 500-metre network buffer around the centroid of every vendor postal code using the Montreal street network. These buffers were intersected with census tracts to assign median household income within the buffer around each vendor, and the contribution of each census tract was weighted based on area. The same procedure was used for metro stations, but a 1-km network buffer was used instead, assuming the greater draw of metro stations (El-Geneidy, Grimsrud, Wasfi, Tétreault, & Surprenant-Legault, 2014). Moreover, the percent of part-time workers was also calculated with the same method since part-time workers may be prone to purchase weekly passes due to the uncertainty of work scheduling. A similar procedure was used to calculate population within the buffer. Finally, categorical variables related to the built environment (metro stations, hub stations, bus stops, commuter stations, and other vendors) were determined as falling within the network buffer or not, and distance to the downtown center point (CBD) was calculated using network analyst in a GIS.

To generate the maps in Figure 2.3, individual points of sale were assigned to the census tract that contributed the greatest area proportion. Then, median income, total monthly fares, total weekly fares, and total three or more purchasers were normalized by calculating *z*-scores for each point of sale. Finally, the *z*-scores for each variable (by point of sale) were summed by census tract and displayed as deciles on a map. Hollow census tracts do not contain points of sale. Note that these maps were used for display purposes, as the unit of analysis is a point of sale and not census tract (or neighbourhood).

2.3.4 Statistical modelling

To account for the variability in transit fare sales between points of sale located within the same census tract, we used multilevel mixed-effects Poisson regression modelling when appropriate (tested with a log-likelihood ratio test). Multilevel modelling acknowledges the hierarchical nature of data, such as individuals nested within different levels like neighbourhoods. Specifically, by accounting for hierarchical relationships, multilevel modelling meets the assumption of the independence of observations that ordinary least square regressions may violate. Multilevel modelling permits allocating the variance to lower (point of sale) and higher (neighbourhood) levels. In other words, if the variance in the data is due to variance between the neighbourhoods, the multilevel technique reports it in the model, while the variance from within the neighbourhood is controlled for and does not affect the other reported variances or the coefficients. The use of this technique is becoming more widespread in social sciences and has been used recently in several publications in the transport field (Djurhuus, Hansen, Aadahl, & Glümer, 2014; Familar, Greaves, & Ellison, 2011; Wasfi, Ross, & El-Geneidy, 2013). In addition, specifying a Poisson model is appropriate for count responses as well as for data with record of no fare transactions. Note that specifying the models as either linear regressions (ln-transformed), multilevel linear regressions, or a multilevel mixed-effects Poisson regressions, by and large yielded similar results in terms of magnitude and sign of the variable of interest, income, demonstrating the stability of the models.

Each point of sale was assigned to a census tract based on the census tract that made the largest area contribution from the GIS-generated network buffer. In Montreal, census tracts are valid proxies for neighbourhoods (Ross, Tremblay, & Graham, 2004). In this study, we used census tracts as a level to visualize and understand the effect of the individual location and neighbourhood characteristics on transit fare sales.

2.4 RESULTS

Table 2.1 lists and describes the variables used in this paper, as well as the summary statistics of the variables. Every point of sale sold an average of 233 weekly passes and 486 monthly passes, suggesting that over the course of a month, more riders buy monthly passes. In terms of recurring weekly pass sales, an average of 13 riders purchased three or more weekly passes at every vendor in

September 2014. Table 2.1 demonstrates that for both types of fares, standard deviations are high indicating a large variation in sales among points of sale.

Table 2.1. Description of Variables and Summary Statistics.

Variable name	Description	Mean	Std. Dev.
Income	Median household income (Canadian dollars) within the buffer (divided by $10,000)	4.50	1.44
Part-time	Percent of workers who are part-time within the buffer	19.77	2.91
Population	Population within the buffer (divided by 1,000)	4.02	1.25
Distance to CBD	Network distance (km) from vendor or metro station to downtown center point	9.62	6.00
Distance to CBD^2	Square-term of network distance to downtown	128.39	168.62
Metro (dummy)	Dummy variable equal to 1 if the point of sale is a metro station	0.15	0.36
Hub (dummy)	Dummy variable equal to 1 if the metro station is a major transfer station or the main downtown station	0.037	0.19
Metro stations	Number of metro stations located within the buffer (excluding the metro station that is the vendor itself)	0.34	0.82
Bus stops	Number of bus stops located within the buffer	25.59	26.87
Commuter stations	Number of commuter stations located within the buffer	0.057	0.26
Other vendor (dummy)	Dummy variable equal to 1 if a vendor (non-metro) is located within the buffer	0.56	0.50
Dependent variable			
Total monthly fares	Total monthly fares (September and October) sold in the month of September	486.69	897.27
ln of total monthly fares	Natural logarithm of total monthly fares (September and October) sold in the month of September	4.91	1.61
Total weekly fares	Total weekly fares (calendar weeks 36, 37, 38, 39 and 40) sold in the month of September	233.05	386.16
IDs 3 or more	Number of unique OPUS IDs purchasing 3 or more weekly fares at unique points of sale	13.26	21.21

N = 407 points of sale (64 Metro/transit stations and 343 vendors); 258 neighbourhoods/census tracts

Figure 2.3a shows that the neighbourhoods with the lowest median incomes (blue hues) are located in the north, southwest, and some central parts of the island. By mapping standardized values (*z*-scores) for monthly fare, weekly fare, and recurring weekly fare purchases, it appears that census tracts with low-incomes had the greatest purchases of all types of fares (red hues, Fig. 2.3b–d). These maps show that vulnerable neighbourhoods are where the transit fare sales are above the mean, consistent with the notion that socially vulnerable groups use public transit the most (Giuliano, 2005; Taylor & Morris, 2015).

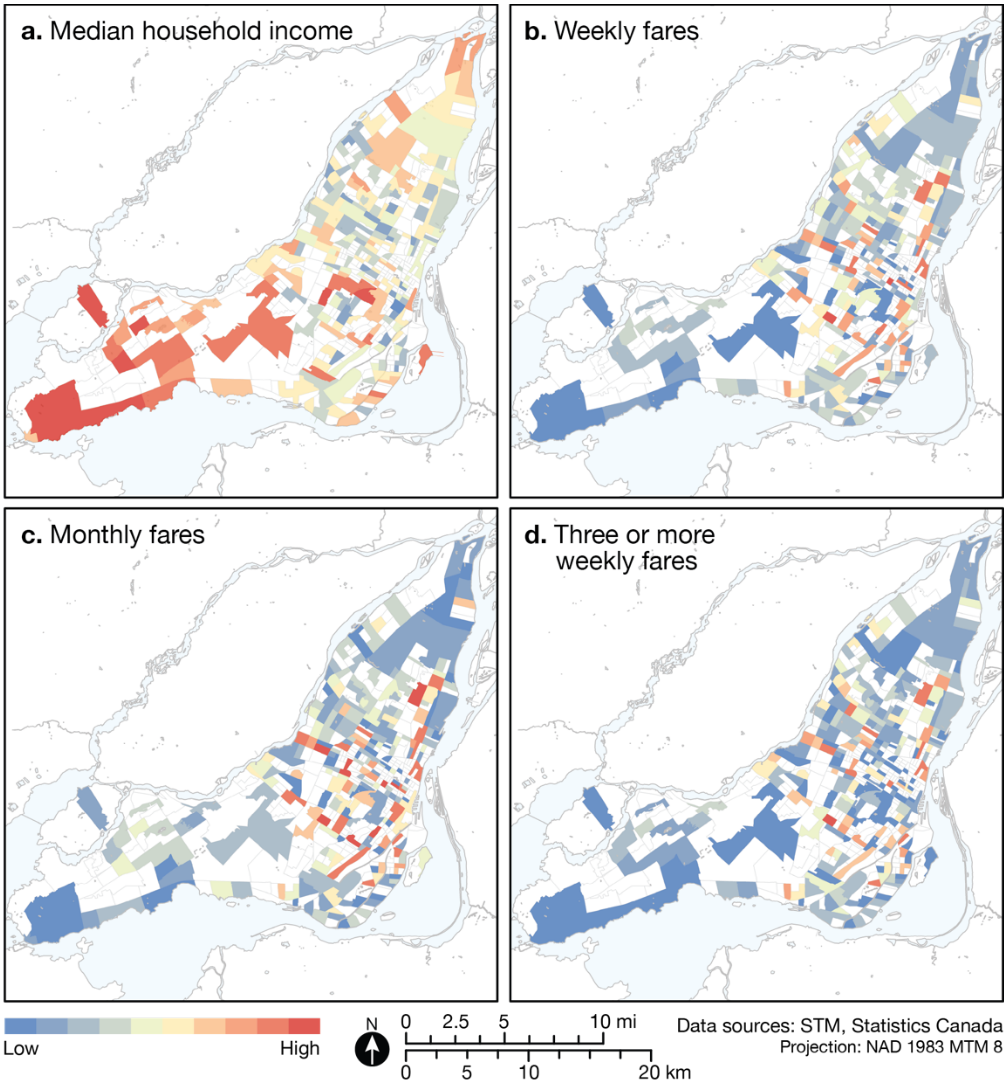

Figure 2.3. Income and fare purchase deciles.

2.4.1 Transit fare purchase models

Using multilevel linear regression modelling at the census tract-level to account for variation between vendors and transit stations located within the same census tract, we developed three different models to determine how different variables contribute to the purchasing of the different fare types. Specifically, we asked how fare purchases at points of sales depend on median income of the neighbourhood surrounding it while controlling for a number of spatial characteristics, such as transit stops and distance to CBD.

First, we analyzed total monthly fare sales using a multilevel linear regression, but found that it was statistically unnecessary (log-likelihood test, P ≥ χ^2 = 0.38) and therefore used a regular linear regression but with a natural logarithmically-transformed dependent variable; this was necessary due to the non-normality of the dependent variable. This model is based on 198,082 total monthly fare transactions from 407 points of sale. Table 3.2 shows the output of the model with median household income as the variable of interest.

Income is not a significant predictor variable of monthly fare purchases, suggesting that individuals with all levels of income buy monthly fares. Moreover, the percentage of part-time workers in a neighbourhood does not impact monthly fare purchases. The control variables show that for every 1,000 residents in a neighbourhood, 16% more monthly fares will be purchased, and distance from the CBD displays a non-linear relationship with monthly fare purchases, so after a certain distance from the CBD (*distance to CBD^2*), 0.25% fewer monthly fares are purchased. If the sales location is a metro station, 239% more monthly fares are sold compared to local vendors, and 1.7% more monthly fares are purchased for every bus stop within the vicinity of the sales point. Model 1 explains 55% of the variation in monthly fare purchases.

Table 2.2. Model 1 – Monthly fare purchase model.

Variable	**Coefficient**	***t*-statistic**	**95% CI Lower bound**	**95% CI Upper bound**
Income	0.0071	0.15	-0.084	0.10
Part-time	0.00059	0.03	-0.039	0.039
Population	**0.16****	**2.84**	**0.049**	**0.27**
Distance to CBD	0.073	1.92	-0.0017	0.15
Distance to CBD^2	**-0.0025***	**-1.98**	**-0.0051**	**-0.00002**
Metro (dummy)	**2.39****	**6.79**	**1.70**	**3.08**
Hub (dummy)	0.57	1.74	-0.075	1.21
Metro stations	-0.081	-0.65	-0.33	0.16
Bus stops	**0.017****	**2.71**	**0.0046**	**0.029**
Commuter stations	-0.26	-1.04	-0.75	0.23
Other vendor (dummy)	-0.072	-0.60	-0.31	0.16
Constant	**3.11****	**5.61**	**2.02**	**4.20**
N	407 points of sale			
Adjusted R^2	0.55			
F statistics	(11, 395) 45.25			
Prob > F	0.00			
AIC	1235.66			
BIC	1283.77			

Bold indicates statistical significance; ** Significant at 99%; * Significant at 95%

Next, we analyzed total weekly fare purchases based on 94,851 transactions from 407 points of sale. First, we specified a multilevel model using total weekly sales transformed as natural logarithms, but needed to add 1 to account for points of sale with 0 weekly fare transactions; running the model as a multilevel was statistically appropriate (log-likelihood test, P ≥ χ^2 = 0.0026). To better account for locations with 0 weekly fare transactions and the non-normality of the dependent variable, we specified a multilevel mixed-effects Poisson regression. The output of Model 2 is reported in Table 2.3.

Table 2.3. Model 2 – Weekly fare purchase model.

Variable	Coefficient	z-statistic	95% CI Lower bound	95% CI Upper bound
Income	**-0.13****	**-7.79**	**-0.17**	**-0.10**
Part-time	**0.095****	**14.14**	**0.082**	**0.11**
Population	**0.10****	**5.58**	**0.067**	**0.14**
Distance to CBD	**0.47****	**20.47**	**0.43**	**0.52**
Distance to CBD^2	**-0.015****	**-16.78**	**-0.016**	**-0.013**
Metro (dummy)	**2.03****	**38.21**	**1.93**	**2.14**
Hub (dummy)	**0.63****	**34.66**	**0.59**	**0.66**
Metro stations	**0.25****	**15.56**	**0.22**	**0.28**
Bus stops	**0.013****	**14.49**	**0.011**	**0.015**
Commuter stations	-0.033	-1.76	-0.070	0.0038
Other vendor (dummy)	0.039	1.87	-0.0020	0.080
Constant	**-0.69***	**-2.63**	**-1.21**	**-0.18**
Census tract – Variance	1.03		0.84	1.25
Number of observations	407 points of sale			
Number of groups	258 census tracts/neighbourhoods			
Log-likelihood	-6121.97			
Prob > χ^2	0.00			
AIC	12269.93			
BIC	12322.05			

Bold indicates statistical significance; ** Significant at 99%; * Significant at 95%

For every $10,000 increase in median income of the neighbourhood is predicted to decrease weekly fare purchases by 13%, suggesting that in neighbourhoods with low incomes, weekly fare sales are greater than in neighbourhoods with high incomes. In addition, every 1% increase in part-time workers residing in the neighbourhood will be expected to increase weekly fare sales by 9.5%, while every 1,000 persons in a neighbourhood will increase total weekly fare sales by 10%. For every 1-km farther from the CBD, there is a 47% increase in weekly fare purchases until a certain distance, where every additional kilometer reduces sales by 1.5%. This suggests that sales locations in inner-city neighbourhoods will sell more weekly fares compared to farther, more suburban neighbourhoods.

Access to mass transit will also increase the purchasing of weekly fares; if the point of sale is a metro station, 203% more weekly fares will be purchased compared to purchases at local vendors, and a hub metro station will sell 63% more weekly fares than local metro stations. Every metro station within the vicinity of a sales location will increase weekly fare purchases by 25%, while every nearby bus stop within the vicinity of a sales location will increase weekly fare purchases by 1.3%. As a general linear model (ln-transformed), Model 2 explains 54% of the variation in total weekly fare purchases.

Finally, we analyzed how recurring weekly fare purchases depend on income. Model 3 (Table 2.4) is based on 5,395 unique purchasers (smartcard IDs) that bought three or more weekly fares during the month. Similar to Model 2 above, Model 3 was specified as a multilevel Poisson regression to account for the non-normality of the dependent variables and locations with no purchasers of three or more weekly fares.

Model 3 reveals that for every $10,000 increase in median household income in a neighbourhood, 24% fewer recurring weekly fare purchases will be made, suggesting that in neighbourhoods with low incomes, more transit riders will buy repetitive weekly fares compared to neighbourhoods with high incomes. Interestingly, while the percentage of part-time workers can increase *total* weekly fares (Model 2, above), the same variable is not significant in the recurrent weekly model, suggesting that part-time workers may purchase weekly fares, but not repetitively to substitute for a monthly fare. Moreover, for every 1,000 persons in a neighbourhood, 11% more recurrent weekly purchases will take place. Every kilometre further from the CBD increases recurrent weekly purchases by 34%, until a given distance, where 0.98% fewer types of these purchases will be made. Recurring purchases will be made significantly more at metro stations, since metro station sale locations will see 199% recurring weekly fare sales compared to local vendors, and 46% more will occur at hub metro stations. Interestingly, the presence of a metro station close by will compete for recurring weekly sales at a vendor of interest, reducing these sales by 16%. The presence of bus stops will also modestly increase the percentage of recurring weekly pass purchases by 1.8%. As a general linear model (ln-transformed), Model 3 explains 56% of the variation in purchasers of three or more weekly fares.

Table 2.4. Model 3 – Three or more recurrent weekly fare purchase model.

Variable	Coefficient	z-statistic	95% CI Lower bound	95% CI Upper bound
Income	**-0.24****	**-5.60**	**-0.32**	**-0.16**
Part-time	0.033	1.84	-0.0022	0.069
Population	**0.11***	**2.46**	**0.022**	**0.20**
Distance to CBD	**0.34****	**8.67**	**0.26**	**0.42**
Distance to CBD^2	**-0.0098****	**-7.04**	**-0.012**	**-0.0070**
Metro (dummy)	**1.99****	**10.65**	**1.62**	**2.36**
Hub (dummy)	**0.46****	**5.94**	**0.31**	**0.62**
Metro stations	**-0.16***	**-2.52**	**-0.29**	**-0.036**
Bus stops	**0.018****	**5.59**	**0.012**	**0.024**
Commuter stations	-0.025	-0.25	-0.22	0.17
Other vendor (dummy)	0.10	1.44	-0.036	0.24
Constant	-1.01	-1.91	-2.05	0.025
Census tract – Variance	0.56		0.44	0.72
Number of observations	407 points of sale			
Number of groups	258 census tracts/neighbourhoods			
Log-likelihood	-1379.75			
Prob > χ^2	0.00			
AIC	2785.50			
BIC	2837.62			

Bold indicates statistical significance; ** Significant at 99%; * Significant at 95%

2.5 DISCUSSION AND CONCLUSION

By modelling transit fare purchase records during September 2014, we discovered that in neighbourhoods with lower median incomes, fare vendors will sell significantly more weekly fares overall, as well as have more purchasers of recurring of weekly fares than vendors in neighbourhoods with higher median incomes. Given that weekly passes in Montreal are more expensive per trip compared to monthly passes, our findings suggest that low income can spur the sale of repetitive weekly fares. Moreover, though the proportion of part-time workers influences overall weekly fare purchases, it is not a significant explanatory variable for recurrent weekly passes, implying that part-time workers may purchase weekly fares due to scheduling, but they are not driving the sale of recurrent weekly fares, supporting the idea that low-income individuals substitute monthly fares for multiple weekly fares (Hickey et al., 2010; Schuerman, 2015). As a consequence, financially vulnerable riders are more likely to be spending more income over the course of a month than riders who can afford to pay for the monthly pass in a single payment. Future work should address how transit agencies strive to balance fares and profits with maximizing ridership and network efficiency.

For vulnerable populations, financial affordability is usually the first hurdle to accessing public transit (Stolper & Rankin, 2016), and access to viable transit for marginalized populations, including residents who lack private cars (Delbosc & Currie, 2012), is necessary to reach jobs and other opportunities (Delbosc & Currie, 2011). As transit agencies regularly increase fares (Hickey, 2005), the burden falls hardest on marginalized groups, in particular when buying monthly fares. The steep upfront cost of a monthly pass may be unaffordable for low-skilled workers who are paid weekly or biweekly (Schuerman, 2015); they may opt instead to buy weekly passes for the entire month. If this is indeed the case, then transit agencies, rather than providing equitable service, are placing an extra penalty on low-income residents by charging more per ride for weekly fares compared to monthly fares.

Our research shows that monthly sales were not influenced by income. This finding aligns with previous work in Athens, Greece that found that income had no effect on bus ridership (Gkritza et al., 2011). In addition, that neighbourhoods in central Montreal show more transit fares sold than suburbs is expected given that metro and bus availability are confined in central Montreal, while suburbs are served mainly by commuter rail that require a different fare that was not included or analyzed in this study. Moreover, sales were largely dependent on whether a point of sale was a metro station or a main hub, such as a transfer station or the main downtown station; transit agencies should ensure sufficient numbers of fare vending machines are available at these types of locations.

Transit agencies increase fares to balance budgets and improve service, but this practice may place extra strain on the neediest riders (Aggarwala, 2012). Since 2013, the STM has increased monthly fares by $2.50 a year, while weekly fares were increased by $0.75 from 2013 to 2014, and again by $1.00 from 2014 to 2015; in comparison to monthly fares, this increase was disproportionately higher for weekly fares. To address fare equity concerns, one potential solution could be to charge the same amount per ride, so that four weekly passes cost the same total price as a 28-day fare, as in Washington, D.C. (WMATA, 2015). In London, fares are capped after a maximum specified number of trips (TfL, n.d.), and having caps that vary by group, like students, seniors or low-income riders, could potentially address equity concerns related to steep upfront costs. Transit agencies in San Francisco, Seattle, and Calgary are examples of agencies that offer fare subsidizes to low-income riders (SFMTA, n.d.; King County Transit, 2015; Calgary Transit, 2015) to decrease the financial burden on socially disadvantaged populations. Using technology already in place with smartcards, the STM could enroll qualifying low-income individuals to be directly eligible for reduced fares, or alternatively, test fare capping.

Our research findings highlight the necessity of conducting fieldwork to uncover the purchasing habits of vulnerable riders. In addition to financial precarity, other vulnerable populations are also transit-dependent, such as single-parents, recent immigrants, and individuals with low educational attainment (Foth et al., 2013; Manaugh & El-Geneidy, 2012). Initially, similar to previous equity work related to accessibility that used an index meant to capture vulnerability at the neighbourhood level (Foth et al., 2013), we also tested a combined social deprivation index and found that results were similar to the models using solely income (data not shown). Therefore, our results indicate that other transit-dependent groups may also purchase multiple weekly fares as a substitute for a monthly fare. Surveys at ticketing locations in areas with socially marginalized populations would lend credence to our assumptions and conclusions. Moreover, future work could attempt to model single fare transactions and its potential relation with social vulnerability. Regardless, a reappraisal of transit fare structure is warranted, since raising fares for high-income riders who can afford to pay more while subsidizing low-income riders may help address not only equity concerns (Stolper & Rankin, 2016), but also address funding shortages and improve transit quality for all (Aggarwala, 2012).

We acknowledge the limitation of analyzing a single month's worth of purchase data. While we wished to study a larger time frame, the intensive time requirements for data extraction limited us to one month's worth of data. An important limitation of our study is that we used neighbourhood-level variables as proxies for demographics of fare purchasers. Although the STM uses smartcards, they, similar to other agencies, do not collect personal information or link such data to smartcard usage (Pelletier, Trépanier, & Morency, 2011; Utsunomiya, Attanucci, & Wilson, 2006). A pilot study collecting a cross-section of transit riders' social profile linked to purchase data could confirm the findings in our study.

CHAPTER 3. HOW AFFORDABLE IS QUALITY PUBLIC TRANSPORTATION FOR MINIMUM WAGE EARNERS IN NORTH AMERICA?

3.1 INTRODUCTION

Urban public transit plays a vital role in society. In addition to providing an important service to residents on a daily basis, which allows them to access employment and other essential services, particularly for people who may not own personal vehicles, public transit contributes to reduced motor vehicular activity, air pollution, energy consumption, and improved road safety, all of which benefit urban populations at large. For riders who depend on transit, affordability of transit fares is crucial; indeed, a recent report on the working poor in New York found that fare affordability was the "biggest problem" of the subway system, ahead of delays and crowding (Stolper & Rankin, 2016). Surprisingly, to our knowledge, little previous research has focused on the financial affordability of public transit, which is an important aspect of accessibility, but rather examines equity related to fare subsidies (Hodge, 1988; Serebrisky, Gómez-Lobo, Estupiñán, & Muñoz-Raskin, 2009). Moreover, public transit agencies in North America typically face funding shortages (US DOT, 2013) and as such, rely a great deal on fare revenue for financial viability (TCRP, 1998). Therefore, a tension exists between the ability of public transit agencies to provide the level of service riders expect while maintaining fares at a socially acceptable level, which in turn allows transit agencies to remain solvent and provide a viable service (Badami & Haider, 2007).

We can think of important objectives and outcomes related to urban public transit from the perspective of, first of all, the travelling public (i.e., transit riders), society at large (since transit provides public goods of benefit to all of society), and the agencies themselves. In this paper, we ask not only how affordable is public transit in the largest 14 cities in North America (population more than 3 million inhabitants), but also how affordability is linked to quality transit service from multiple perspectives. To this end, we investigated how well transit agencies meet the various objectives important to riders, society and to the agency themselves, and then compare performance to the affordability of this service to minimum-wage earners. In doing so, this paper uses publicly and freely available data reported by public transit agencies. The output from this process has the advantage of allowing researchers, transport planners, as well as interested members of civil society the ability to assess the affordability and quality of an agency of interest compared to peer agencies without the need for costly and proprietary surveys (Randall, Condry, & Trompet, 2007).

This paper begins with a brief literature review of previous studies concentrating on transit quality as it relates to diverse perspectives, as well as transit affordability. The second section of the paper describes the rationale for each indicator and how the indicators are constructed. In the third section of the paper, we describe the major findings based on different quality of service indicators in relation to affordability. In the final section, we discuss the implications of our findings, and how the methodology for such an assessment may be improved in future work.

3.2 LITERATURE REVIEW

The dilemma of achieving contrasting goals—providing quality service that is affordable, while being profitable or cost efficient (Badami & Haider, 2007)—requires the acknowledgement of different stakeholders involved in public transit and their sometimes divergent interests. The Transit Cooperation Research Program (TCRP) *Transit Capacity and Quality of Service Manual* provides a primer on quality of service measures and concepts (TCRP, 2013), and as such, describes four different, and somewhat, overlapping groups with interests in public transit quality or performance: customer, community, agency, and motorists who interact with but are not taking public transit (TCRP, 2013). Customer preferences relate to two broad factors—service availability, and comfort and convenience. Service availability depends on the frequency of service, on the hours of available service or service span, and on the accessibility to transit stops or stations (TCRP, 2013). And while transit riders may be choice riders, implying that these individuals choose to use transit instead of driving a private vehicle, or transit-dependent riders who have no other option but to use transit (Krizek & El-Geneidy, 2007), comfort and convenience are important to both types of riders and can impact satisfaction and usage (Eboli & Mazzulla, 2011; Verbich & El-Geneidy, 2016). Comfort can result from the passenger load and seat availability, the duration of the trip itself, driver friendliness, and reliability of the service. Indeed, a large body of evidence based on customer satisfaction surveys reiterates the importance of reliability, frequency, comfort, and safety to transit riders (Das & Pandit, 2016; de Oña, de Oña, Eboli, & Mazzulla, 2013; dell'Olio, Ibeas, & Cecin, 2011; TCRP, 2013). When agencies are able to provide transit service that closely aligns with rider expectations, transit agencies provide benefits to society at large by allowing individuals, in particular those without vehicles, to move around a city, as well as help reduce pollution and congestion.

Indeed, from a societal point of view, an important outcome is the extent to which transit agencies are able to carry people (APTA, 2016); more particularly, the extent to which they are able to replace car trips, because that determines the extent to which urban public transit contributes to the production of public goods (in terms of air pollution, congestion, road safety, etc.). From the view point of an agency, and particularly if the agency is funded through taxpayer revenues, it is important that transit contributes to the achievement of the objectives and outcomes of importance to commuters and society at large, while also being financially viable (TCRP, 2013). Indeed, urban transit agencies face what might be considered a coverage-affordability-viability dilemma—that is, there is a potential trade-off between their ability to provide widespread coverage, and to do so affordably for commuters, while also being financially viable.

A well-used transit service is beneficial to society at large, certainly the agency, and riders as well; therefore, many features valued by one group may also be important to another, and are difficult to unequivocally classify as one group's interest over another's. While passengers may be unaware or unconcerned with aspects like cost effectiveness or ridership of a route, for instance, these measures are priorities for agencies and directly impact the service quality riders' experience. Operating revenue for transit service is derived from a variety of sources, such as government funding, advertisement and other revenues, and importantly, fare revenues. Fare revenue makes up 25% of the total budget of agencies in regions with populations greater than 200,000, and fares contribute 33%—the largest single source—to operating expenses (TCRP, 2009). Not surprisingly then, transit agencies rely a great deal on fares, and these fares have outpaced inflation in the United States between 1989–1994 (TCRP, 1998). In Canada, limited federal funding means that for transit agencies, operating expenses are mostly covered through provincial funding and locally generated revenues and fares. For example, in Montreal, 41% of the 2016 operating budget (a little over $1.5 billion (CAD)) of the Société de transport de Montréal (STM) comes from fares, while 34% comes from local and regional governments, while nearly 23% is provided by the provincial government, and about 2% coming from other sources (STM, 2015b). In the United States and Canada, farebox revenue is thus a crucial budget item. This significant dependence on transit fares, coupled with increasing expenditures, forces agencies to attempt to maximize revenue but maintain fares at an acceptable level—a viability-affordability dilemma (Badami & Haider, 2007). While raising transit fares may be necessary for transit viability, fare increases may also overburden low-income groups as many of them rely on public transit as a main mode of transport (APTA, 2007; Stolper & Rankin, 2016).

Affordability studies of public transit have been scarce. In a Word Bank publication, Carruthers, Dick, and Saurkar (2005) derived a simple and useful metric to assess transit affordability among developing and developed countries. This affordability index assumes 60 ten-kilometre trips (single fares) per month expressed as a percentage of average annual per capita income of a city. On this basis, they determined that residents of Latin American cities spend, on average, between 4–11% of annual income on transit, while residents of Western cities spend, on average, less than 5%. They also repeated this exercise for the bottom quintile earners and discovered that residents in Western cities spend upwards of 10% of income on transit, while residents in Latin American cities spend more that 25% of their annual income on transit (Carruthers et al., 2005). Recent work has used Gini coefficients based on the cumulative distribution of transport benefits to determine how different groups, such as students or the elderly, benefit or lose based on different subsidy policies for transit fares (Serebrisky et al., 2009). Nonetheless, deciding upon an acceptable level of income devoted to transport is not trivial

(Gómez-Lobo, 2011). Therefore, beyond the importance of the quality of public transit performance for riders, society, and agencies, affordability of public transit is also crucial, particularly for vulnerable residents (Stolper & Rankin, 2016).

Based on this overview of the literature, it is clear that multiple perspectives are involved in public transit outcomes and an intricate balance is needed to achieve sometimes conflicting goals, namely quality service for an affordable price. Figure 3.1 schematizes the relationship between the fares that transit riders pay which play a role in determining the service quality provided by a transit agency, and how the service quality can determine the transit fare charged by an agency. As such, a transit agency needs to balance the quality of factors like accessibility, frequent service, and comfort with affordability. In the end, society accumulates multiple benefits from a viable public transport service.

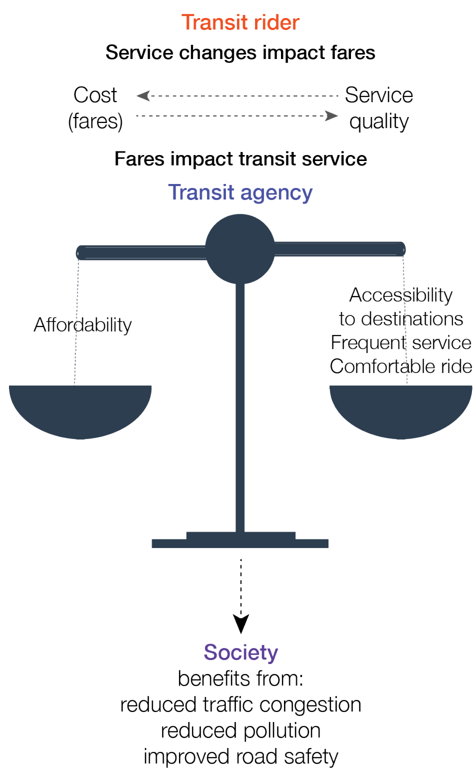

Figure 3.1. Balancing affordability and transit service quality from multiple perspectives.

3.3 METHODOLOGY

The current paper is concerned with the public transport service residents in large (3 million inhabitants and more) North American cities have access to. Importantly, this paper is not a comprehensive evaluation or benchmarking study of transit agencies per se, but rather aims to assess how transit service quality may vary with transit affordability.

Determining a peer group for transit agency comparative studies is not a trivial task, and the research goal should inform inclusion and exclusion criteria. First, we limited the agencies included in this analysis to the main transit service providers of the largest North American cities, those with metropolitan populations greater than 3 million inhabitants. It is important to note that the population of the core city itself may be actually quite small. We also restricted our analysis to agencies that operate at least two modes, namely bus and rail, including light rail, heavy rail (metro or subway), and/or street rail (cable car, streetcar, etc.). Since the main concern of this study is urban transit, we excluded agencies providing commuter rail service only and commuter rail data from agencies included in this study. In total, we analyzed data from 14 transit agencies, including two from Canada and 12 from the United States. Table 3.1 lists, in order of decreasing metropolitan population, the cities and agencies examined in this paper.

Table 3.1. Cities and transit agencies.

Metropolitan area	Core city	Metropolitan population	Transit Agency	Modes
New York-Northern New Jersey-Long Island, NY-NJ-PA	New York	18,351,295	MTA New York City Transit (NYCT)	Heavy rail, bus
Los Angeles-Long Beach-Santa Ana, CA	Los Angeles	12,150,996	Los Angeles County Metropolitan Transportation Authority (LACMTA)	Heavy rail, light rail, bus
Chicago-Joliet-Naperville, IL-IN-WI	Chicago	8,608,208	Chicago Transit Authority (CTA)	Heavy rail, bus
Toronto (Mississauga), ON	Toronto	5,521,235	Toronto Transit Commission (TTC)	Heavy rail, light rail, street rail, bus
Miami-Ft. Lauderdale-Pompano Beach, FL	Miami	5,502,379	Miami-Dade Transit (MDT)	Heavy rail, bus
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	Philadelphia	5,441,567	Southeastern Pennsylvania Transportation Authority (SEPTA)	Heavy rail, street rail, bus
Dallas-Fort Worth-Arlington, TX	Dallas	5,121,892	Dallas Area Rapid Transit (DART)	Light rail, bus
Houston-Sugar Land-Baytown, TX	Houston	4,944,332	Metropolitan Transit Authority of Harris County (Metro)	Light rail, bus
Washington-Arlington-Alexandria, DC-VA-MD-WV	Washington	4,586,770	Washington Metropolitan Area Transit Authority (WMATA)	Heavy rail, bus
Atlanta-Sandy Springs-Marietta, GA	Atlanta	4,515,419	Metropolitan Atlanta Rapid Transit Authority (MARTA)	Heavy rail, bus

Metropolitan area	Core city	Metropolitan population	Transit Agency	Modes
Boston-Cambridge-Quincy, MA-NH-RI	Boston	4,181,019	Massachusetts Bay Transportation Authority (MBTA)	Heavy rail, light rail, bus
Montreal (Laval), QC	Montreal	3,752,475	Société de transport de Montreal (STM)	Heavy rail, bus
San Francisco-Oakland-Fremont, CA	San Francisco	3,281,212	San Francisco Municipal Railway (SFMTA)	Light rail, street rail, bus
Seattle-Tacoma-Bellevue, WA	Seattle	3,059,393	King County Department of Transportation (King County Metro)	Street rail, bus

After selecting peer agencies, we next turned to choosing key indicators meant to capture the experience and service that matter to riders, operators, and society. As far as riders are concerned, outcomes that are crucially important are availability and accessibility; frequency and reliability; comfort and convenience; and affordability (p. 9, RPA (2015)). To put it succinctly, riders are looking for high service quality, in terms of the first three sets of outcomes, but which is also affordable. Unfortunately, comparable data to capture accessibility, and frequency and reliability, are extremely difficult to obtain or to generate for all of the metropolitan areas that we have chosen for this paper; these measures will need to be developed in the future. For instance, frequency and reliability (related to waiting time) are two chief concerns of transit riders (Diab, Badami, & El-Geneidy, 2015) and tracked by many agencies (New York City Transit and Bus Committee, 2016; STM, 2016; TTC, 2016), but agencies do not adhere to a uniform measure of reliability making comparisons difficult, in addition to not reporting disaggregated statistics. At present, we used publicly available data to come as close as possible to approximating four main features that are measurable and important to riders—accessibility, service frequency, comfort, and affordability.

Travel on transit, or any other mode for that matter, is typically a derived demand for access to some desired destination. As such, accessibility measures provide a good indication of the potential ability to reach desired destinations, like jobs, health services, or schools, based on a travel mode and influenced by land use (El-Geneidy & Levinson, 2006; Geurs & van Wee, 2004). Therefore, we used accessibility measures to jobs by transit within a 30-minute travel time threshold to assess access to jobs. Values from American cities were from the *Access Across America* report (Owen & Levinson, 2014), while accessibility in Canadian cities were derived from previous work (El-Geneidy et al., 2015;

El-Geneidy et al., 2016). Note that accessibility data from Owen and Levinson (2014) were calculated using all public transit agencies in a region, while our focus here is the main transit agency of a city; the agencies analyzed here, as the main agency in each city, likely contribute the greatest to the accessibility measures used.

To approximate service frequency, we downloaded General Transit Feed Specification (GFTS) data for all agencies for a date in fall 2014 in order to avoid summer or winter holiday scheduling and calculated scheduled headways. Headways for all modes operated (≥60 s) were calculated at the stop-level for stops scheduled from 8:00 a.m. to 8:59 a.m. and from 9:00 p.m. to 9:59 p.m. for weekdays. Next, 500 random headways (or fewer if 500 stops were not made) were extracted for the two time periods and average headway was calculated for each time period. While these values are approximations of actual headways, they nevertheless may provide an indication of service frequency at two different times of the day.

As for comfort and convenience, load factor—the ratio of passenger kilometres to carrying capacity kilometres, expressed as a percentage, with capacity kilometres being obtained by multiplying the total seating and standee capacity of all buses by the kilometres operated—would be a good measure for this purpose. Unfortunately, load factor data (or the total capacity on the transit fleet) is not available for the various agencies in North America, so we chose to estimate a proxy measure of crowding on transit vehicles of all modes (and thus, the space available, and comfort and convenience for commuters), which is the ratio of passenger kilometres to revenue kilometres. Note that, while from a rider perspective, a greater value of this ratio is undesirable since it indicates less room on transit, a high figure might be good from the agency perspective.

A previous study from the World Bank Group examined the affordability of public transit in developing countries (Carruthers et al., 2005), and provided a snapshot of the amount of income dedicated to transit for the average resident of a city. Here, we are interested in determining the affordability for transit-dependent riders, in particular those who earn a minimum wage. These residents would likely rely on public transit (APTA, 2007) and we assumed that a monthly pass would be the most frugal fare to purchase if one commutes daily, as well as to enable comparability between agencies. Thus, we used monthly fare (in 2014) and minimum wage (in 2014) in local currency and developed an indicator to express the number of minimum wage hours needed to purchase a one-month unlimited fare (fare divided by hourly minimum wage). Taxes on the fare and on income were not included in the calculations.

For society as a whole, as discussed earlier, an important outcome is the extent to which transit agencies are able to carry people, as a proportion of the total population, but more particularly, the extent to which they are able to replace car trips; so, an ideal measure for this purpose would be total transit trips divided by the product of the population in the service area and the car ownership rate. However, since car ownership rate is not available in a disaggregated fashion for all of the cities in our analysis, we use total unlinked trips divided by the service area population as our measure. Finally, the measure we chose to capture the key outcome from the agency's perspective is the farebox recovery ratio—that is, the share of operational costs recovered through farebox revenues.

All data except for headways were acquired through the National Transit Database (NTD) for American agencies and from the Canadian Urban Transit Association (CUTA) for Canadian agencies. Data were collected disaggregated by mode to avoid collecting statistics for modes other than bus, heavy rail (metro or subway), light rail, and/or street rail; data by mode were then summed. Minimum wages for American cities were acquired through a website listing wages by city and state (Dolye, 2015), and verified by checking with other sources, while Canadian minimum wages were acquired through a Canadian governmental website (Government of Canada, 2016).

To address the different perspectives involved in public transit, we borrow from multicriteria decision making (MCDM) analysis, since this approach is amenable to evaluating complex issues involving different stakeholders with conflicting objectives, as well as providing a transparent process. Importantly, MCDM analysis compels one to clarify goals and outcomes, and as such, develop indicators or metrics that are measurable, objective, and reliable (Hobbs & Horn, 1997; Ingram, 2009; Manaugh et al., 2015). For the present study, we take the MCDM approach to analyze outcomes important to transit riders, society at large, and transit agencies. When combining individual metrics, such as frequency and FRR, we normalized the values for each agency by using the form of a single attribute utility function and by assuming linearity of this function over its range between the worst and best values (Hobbs & Horn, 1997).

The *accessibility indicator* is the normalized average number of jobs reachable by public transit within a 30-minute travel time threshold (weighted by number of workers in each census tract or block) and the greater the number of jobs the better. A combined *headway indicator* was generated by summing the two individual normalized values of headways at 8 a.m. and 9 p.m. and then dividing by two and rescaling; a larger value of this indicator indicates better (shorter) headways. The *comfort indicator* is simply the normalized value of total passenger kilometres divided by total revenue kilometres; larger values of this indicator suggests fewer passengers per revenue kilometre or more space for a rider and is ‘better’. A final composite indicator, called the *rider indicator*, was composed by summing the accessibility indicator, the headway indicator, and the comfort indicator, and dividing by three, and finally rescaling. Note that none of the indicators were weighted when calculating this composite indicator. The *society indicator* is the normalized value of the total unlinked ridership divided by service area population, where larger values are ‘better’. The *agency indicator* is the normalized FRR, which was calculated by dividing total fare revenue by total operating expenses for only modes analyzed here; greater FRR is 'better'. In the graphs below, normalized values are plotted only when indicators are combined, otherwise, raw values are plotted.

3.4 RESULTS AND DISCUSSION

3.4.1 Rider perspective

Table 3.2 lists raw values of the indicators aimed at capturing the essence of riders’ desires in a public transit service. Table 3.2 also lists the normalized values of each indicator, calculated with a form of a single attribute utility function (Hobbs & Horn, 1997), which were subsequently used to derive a composite rider indicator. Agencies are listed from best to worst performing from the composite rider indicator, which is an unweighted average of the accessibility, headway, and comfort indicators.

Table 3.2. Transit rider indicators.

City	Transit agency	Ridership (unlinked trips, '000)	Avg. accessibility (jobs)	Accessibility indicator (*a*)	Avg. 8 a.m. headway (min)	Avg. 9 p.m. headway (min)	Headway indicator (*b*)	Avg. pass km/rev. km	Comfort indicator (*c*)	Rider indicator (*a*+*b*+ *c*/3)
New York	NYCT	3,631,168	210,186	1.00	8.55	13.86	0.73	28.53	0.00	1.00
Chicago	CTA	466,658	48,116	0.20	8.84	13.57	0.73	17.31	0.62	0.81
Toronto	TTC	514,216	60,676	0.26	5.80	7.48	1.00	23.48	0.28	0.81
San Francisco	SFMTA	857,806	65,246	0.29	9.06	13.77	0.71	21.94	0.36	0.62
Boston	MBTA	99,108	49,237	0.21	8.18	14.39	0.73	20.89	0.42	0.61
Philadelphia	SEPTA	301,146	35,317	0.14	8.99	19.57	0.56	16.85	0.65	0.60
Houston	Metro	66,842	15,166	0.04	15.24	21.85	0.28	10.47	1.00	0.57
Seattle	King County Metro	72,694	26,141	0.09	13.04	17.38	0.48	15.11	0.74	0.57
Montreal	STM	409,197	70,683	0.31	8.79	12.97	0.75	23.94	0.25	0.57
Miami	MDT	128,539	15,333	0.04	10.87	17.96	0.54	16.55	0.66	0.49
Washington, D.C.	WMATA	359,715	47,759	0.20	13.94	20.20	0.37	17.08	0.63	0.45
Dallas	DART	698,473	10,113	0.02	19.89	26.22	0.00	10.97	0.97	0.23
Los Angeles	LACMTA	155,317	43,430	0.18	12.72	18.86	0.45	22.26	0.35	0.21
Atlanta	MARTA	101,352	6,995	0.00	20.90	20.77	0.12	16.72	0.65	0.00
	Average	–	50,307	–	11.78	17.06	–	18.72	–	–
	Standard deviation	–	50,480	–	4.48	4.72	–	5.05	–	–
	Coefficient of variation	–	1.00	–	0.38	0.29	–	0.27	–	–

Accessibility to jobs by transit helps explain the efficiency of a transit system to deliver workers to jobs—a critical role of public transit (Foth et al., 2013). Accessibility values during the morning peak to jobs by transit within a 30-minute threshold were derived from *Access Across America*, and calculated for Toronto and Montreal by weighting job accessibility by the number of workers (per census tract), and averaged over the metropolitan region. We caution that because of different geographical scales and methods (average accessibility over 7–9 a.m. for American cities vs. accessibility at 7 a.m. for Canadian cities), and since these measures encompass all transit modes (including commuter rail), the accessibility measures likely overestimate the accessibility of the particular agencies examined here. Regardless, they provide a useful comparison (Table 3.2). New York's transit system offers the largest accessibility to jobs, while Montreal’s transit agency, the STM, offers the second best accessibility to jobs. Atlanta’s transit agency, MARTA, offers its residents the lowest accessibility to jobs in the cohort. Unsurprisingly, headways are shorter in the morning peak than in the evening hours. The TTC has the shortest average headways during both time periods, while MARTA has the longest headways during the morning peak, and DART has the longest headways at off-peak evening hours (Table 3.2). Interestingly, most agencies with short headways perform poorly on the comfort indicator, such that the TTC, for instance, has 23.48 passenger kilometres per revenue kilometres, while Houston's transit agency, Metro, DART, and MARTA have long headways, but few passenger kilometres per revenue kilometres. These three individual indicators were normalized, averaged in an unweighted manner, and finally rescaled to yield the composite rider indicator and ranked from best to worst performing (Table 3.2). NYCT, the CTA, and TTC are the top performing, while DART, the LACMTA, and MARTA at the bottom performing transit agencies from a rider perspective.

Table 3.3 reports the cost of a monthly fare, hourly minimum wage, the number of hours of minimum wage work needed to purchase a transit fare, as well as a normalized affordability indicator (fewest hours needed to afford a monthly fare is 'best' or 1.00). Note that values are in local currency and from 2014. The transit agencies with fares that are most affordable for minimum wage earners are the SFMTA, the STM, and the LACMTA. The least affordable agencies—those with fares that require most hours of minimum wage work—are NYCT, MDT, and WMATA.

Table 3.3. Transit agencies, fares, minimum wages, and affordability.

City	Transit agency	Monthly fare ($) (*a*)	Hourly minimum wage ($) (*b*)	Hours to purchase fare (*a*/*b*)	Affordability indicator
San Francisco	SFMTA	68.00	10.74	6.33	1.00
Montreal	STM	79.50	10.35	7.68	0.93
Los Angeles	LACMTA	75.00	9.00	8.33	0.89
Seattle	King County Metro	81.00	9.32	8.69	0.87
Boston	MBTA	75.00	8.00	9.38	0.84
Dallas	DART	80.00	7.25	11.03	0.75
Chicago	CTA	100.00	8.25	12.12	0.69

City	Transit agency	Monthly fare ($) (*a*)	Hourly minimum wage ($) (*b*)	Hours to purchase fare (*a*/*b*)	Affordability indicator
Toronto	TTC	133.75	11.00	12.16	0.69
Houston	Metro	90.00[a]	7.25	12.41	0.67
Philadelphia	SEPTA	91.00	7.25	12.55	0.67
Atlanta	MARTA	95.00	7.25	13.10	0.64
New York	NYCT	112.00	8.00	14.00	0.59
Miami	MDT	112.50	7.93	14.19	0.58
Washington	WMATA	237.00[b]	9.50	24.95	0.00
			Average	11.92	
			Standard deviation	4.48	
			Coefficient of variation	0.388	

[a] The Houston transit agency does not have a monthly fare, so the maximum daily unlimited fare ($3.00) was simply multiplied by 30 days. [b] While WMATA has an array of monthly fares available by mode, maximum price of a trip, etc., this fare was chosen to be comparable with other agencies, i.e., offering unlimited travel for a 30-day period.

In Figure 3.2, we plotted the different indicators from Table 3.2 against the affordability indicator from Table 3.3 to visualize the interplay between affordability and service quality attributes. Note in the following figures, marker sizes represent unlinked passenger trips to provide an understanding of the volume of passengers handled by each system.

In terms of accessibility, New York's transit system (NYCT, agency 1) offers the highest accessibility to jobs at a slightly unaffordable cost (Fig. 3.2a). Montreal's transit agency, the STM (agency 12), offers the second best accessibility to jobs and is also the second most affordable agency in the cohort. While WMATA (agency 9) offers relatively good accessibility, it is the least affordable of the cohort. Overall, the most affordable agencies tend to offer low accessibility.

In Figure 3.2b, many agencies have shorter headways with affordable service, including agencies in Boston, San Francisco, Montreal. On the other hand, Atlanta's transit agency is expensive despite having longer headways, given that 13.10 hours of minimum wage work is required to purchase a monthly pass, compared to the average 11.92 hours of the sample. Washington, D.C.'s transit agency, WMATA, has relatively long headways and is the least affordable of the agencies analyzed here. To make matters worse, due to increasing operating costs outpacing operating revenue, WMATA has recently considered increasing fares, as well as increasing already long headways to maintain fiscal viability (Duggan, 2014).

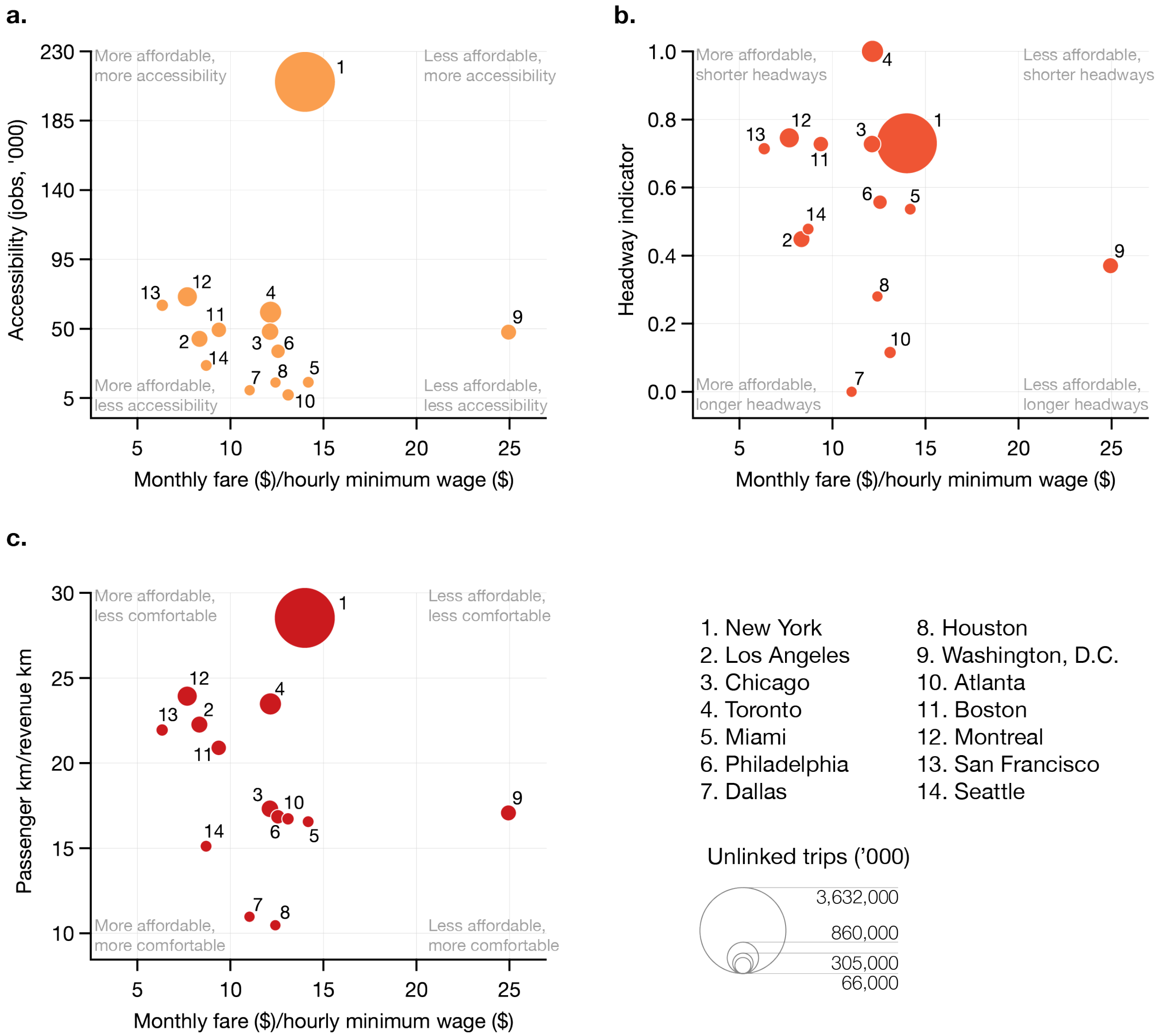

Figure 3.2. Accessibility, headway, and comfort indicators plotted against a measure of affordability. Note that only headway is normalized since this indicator is composed of two measures (headways at peak and off-peak hours).

In addition to frequent service, being comfortable on-board is also important for riders (dell'Olio et al., 2011; Diab et al., 2015). As shown in Figure 3.2c, DART (agency 7) and Metro (agency 8) have few passenger kilometres per revenue kilometres, suggesting that riders will be relatively more comfortable than on transit in New York (agency 1). DART and Metro also offer somewhat affordable transit. Overall, systems with high ridership, indicated by the size of the markers, offer lower comfort that may be affordable, like in Montreal and San Francisco, or more expensive like in New York and Chicago.

3.4.2 Society and transit agency perspectives

From a societal perspective, a well-used public transit system can be ascertained by analyzing ridership per capita, an indication of the usage of a particular transit system due to quality service (TLS, 2014). Table 3.4 lists the raw and normalized values for ridership per capita and ranks them from greatest to least. The top three used systems, on a per capita basis, are NYCT, the STM, and the TTC. The least used systems are those found in historically car-dependent cities in the United States, such as in Los Angeles, Miami, Dallas, and Houston. In particular, transit in Los Angeles has low usage despite its relative affordability for minimum wage earners (third most affordable) and investment and rail expansion (Linton, 2016; Nelson & Weikel, 2016). This low per capita usage for LACMTA is likely related to long headways and poor job accessibility, and can explain the high comfort indicator (see Fig. 3.2).

Table 3.4. Ridership per capita and society indicator.

City	Transit agency	Ridership per capita	Society indicator
New York	NYCT	427.65	1.00
Montreal	STM	360.41	0.84
Toronto	TTC	305.43	0.70
San Francisco	SFMTA	192.88	0.42
Chicago	CTA	150.09	0.32
Washington	WMATA	110.01	0.22
Philadelphia	SEPTA	89.76	0.17
Boston	MBTA	86.04	0.16
Atlanta	MARTA	79.71	0.14
Los Angeles	LACMTA	54.09	0.08
Seattle	King County Metro	49.57	0.07
Miami	MDT	39.70	0.05
Dallas	DART	27.42	0.02
Houston	Metro	19.67	0.00
	Average	142.32	–
	Standard deviation	131.34	–
	Coefficient of variation	0.92	–

For the long-term ability to serve rider and society objectives, it also necessary that transit service be financially viable or else fiscal issues can arise and service may suffer. A common measure of financial efficiency is FRR, and Table 3.5 lists FRR and normalized values (agency indicator), ranked from agency with best recovery to agency with the worst recovery. Interestingly, the two Canadian agencies in the sample, the TTC and STM, are the best performing for FRR, as the TTC recovers 71% of its revenue from fares, while the STM recovers 56%. NYCT is close in third place at 51% recovery. The lowest performing agencies for FRR are in southern American cities, including the LACMTA, DART and Metro. Indeed, funding for Metro (in Houston) comes largely through sales tax revenue (METRO, 2015). Moreover, agencies with high FRRs are those with high ridership, short headways, and good accessibility, but not necessarily the highest fares; while the TTC is in the middle for affordability, the STM is second most affordable and has the second best FRR, while NYCT and WMATA are expensive but have the third and fourth best FRRs, respectively.

Table 3.5. Farebox recovery ratio (FRR) and agency indicator.

City	Transit agency	FRR	Agency indicator
Toronto	TTC	0.71	1.00
Montreal	STM	0.56	0.75
New York	NYCT	0.51	0.67
Washington	WMATA	0.48	0.62
Chicago	CTA	0.44	0.55
Boston	MBTA	0.40	0.49
Philadelphia	SEPTA	0.36	0.41
Seattle	King County Metro	0.33	0.36
Atlanta	MARTA	0.31	0.33
Miami	MDT	0.28	0.27
San Francisco	SFMTA	0.26	0.25
Los Angeles	LACMTA	0.25	0.23
Dallas	DART	0.15	0.06
Houston	Metro	0.12	0.00
	Average	0.37	–
	Standard deviation	0.16	–
	Coefficient of variation	0.44	–

3.4.3 Overall service quality

To determine the overall quality from the rider perspective and how it relates to affordability, we averaged all the individual indicators—accessibility, headway, and comfort—and rescaled the average value to derive a service quality indicator pertinent to riders (rider indicator) and plotted it against affordability (Fig. 3.3a). This represents the key trade-off from the perspective of transit riders who desire quality service that is affordable.

The majority of agencies analyzed here offer good quality service that is somewhat affordable (Fig. 3.3a). For instance, Chicago's agency, the CTA (agency 3), and the TTC (agency 4) in Toronto offer excellent service that is somewhat affordable, while the most affordable agency, SFMTA (agency 13) in San Francisco, also provides good service. The second most affordable agency, the STM (agency 12) in Montreal, provides somewhat good quality service comparable to agencies in Philadelphia (agency 6), Houston (agency 8), and Seattle (agency 14), but that is more affordable for minimum wage earners. Also, while transit in Philadelphia, Houston, Chicago, Toronto, and Atlanta have comparable affordability, service quality varies drastically. On the other hand, transit in Los Angeles (agency 2), Dallas (agency 7), and Atlanta (agency 10), while being somewhat affordable, have the lowest service quality for riders in the cohort. Finally, WMATA (agency 9) in Washington, D.C. is expensive compared to all other agencies and the quality of service is in the mid-lower section in terms of rider expectations.

From a societal viewpoint, the STM (agency 12, Fig. 3.3b) provides the second most ridership per capita that is also second most affordable. The TTC and NYCT too provide significant public benefits but at a higher cost to minimum wage earners. Overall, a sizeable number of agencies cluster in the lower left-hand portion in Figure 3.3b, suggesting that while agencies provide relatively affordable service, they offer low ridership per capita (also see Table 3.4).

The top performing agency from a financial standpoint is the TTC in Toronto, and is seventh most affordable, while the STM in Montreal is the second best agency at recovering revenues from fares while being second most affordable (Fig. 3.3c). The agency that is most affordable, SFMTA, ranks low (11^{th}) in FRR. While NYCT is third best at recovering revenues from fares and WMATA in Washington, D.C. ranks fourth, they are the least affordable agencies (12^{th} and 14^{th}, respectively). Interestingly, MDT in Miami, is 10^{th} for the agency indicator, and is the 13^{th} most affordable agency, suggesting that it is both expensive and financially precarious (Fig. 3.3c). Many of the agencies analyzed here are either expensive and recover a low amount of revenue from fares (Metro, WMATA, MARTA, for example), expensive and have a higher FRR (TTC and NYCT), or rather affordable but with a low FRR (SFMTA and LACMTA, for example); the STM in Montreal stands out as a financially viable system with an affordable fare for minimum wage earners.

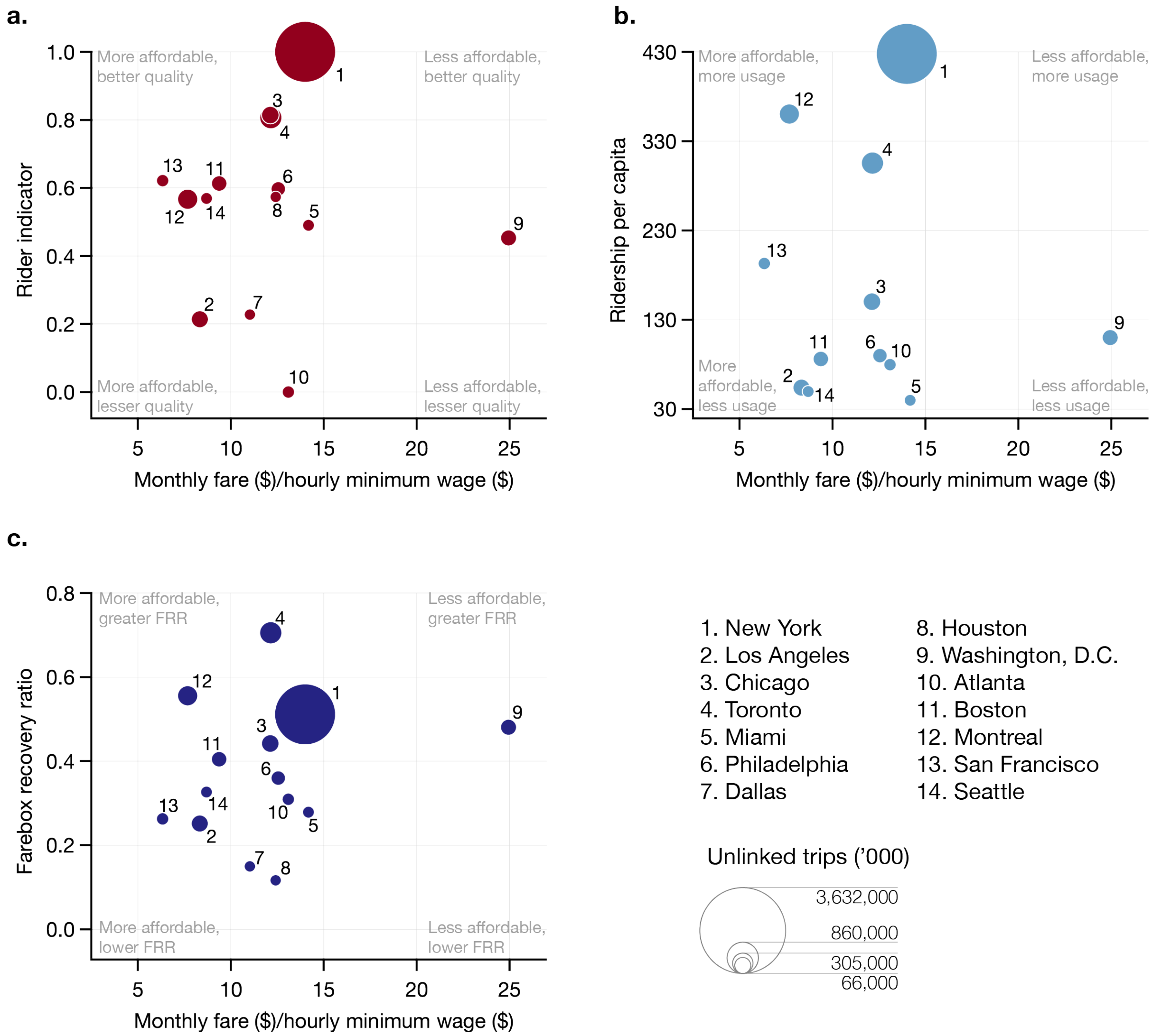

Figure 3.3. Rider, society, and agency indicators plotted against a measure of affordability.

Finally, we summed the rider indicator, the society indicator, and the agency indicator, averaged and re-normalized the values to obtain a *service quality indicator* listed in Table 3.6. The agencies are ranked from best to worst overall performing, and the affordability indicator (minimum wage hours needed to afford a monthly fare) is also listed for comparison and convenience. Moreover, Figure 3.4

represents this relation graphically. The top performing agency is NYCT, based on excellent rider and society indicators; however, buying a monthly fare requires 14 hours of minimum wage work. The TTC ranked second based on strong rider and agency indicators, and requires 12 hours of minimum wage work to afford a monthly fare. In third place, the Montreal transit agency, the STM, performs well in the society and agency indicator, while is about average for the rider indicator. Nevertheless, it is the second most affordable (~8 hours of minimum wage work to purchase a monthly fare) out of the top-five performers; only the SFMTA is more affordable and placed fifth. The CTA in Chicago, with a strong rider indicator, ranks fourth but is roughly equivalent to the TTC in terms of affordability. Finally, out of the bottom three performers, save for MARTA in Atlanta, both the DART in Dallas and the LACMTA in Los Angeles offer relatively affordable service, but that is of lower quality. Therefore, from the view of quality and affordability, the STM and SFMTA are the best performers from the cohort.

Table 3.6. Final ranking, service quality indicator and affordability

City	Transit agency	Rider indicator	Society indicator	Agency indicator	Service quality indicator	Hours to purchase fare
New York	NYCT	1.00	1.00	0.67	1.00	14.00
Toronto	TTC	0.81	0.70	1.00	0.86	12.16
Montreal	STM	0.57	0.84	0.75	0.74	7.68
Chicago	CTA	0.81	0.32	0.55	0.56	12.12
San Francisco	SFMTA	0.62	0.42	0.25	0.43	6.33
Boston	MBTA	0.61	0.16	0.49	0.37	9.38
Washington	WMATA	0.45	0.22	0.62	0.36	24.95
Philadelphia	SEPTA	0.60	0.17	0.42	0.35	12.55
Seattle	King County Metro	0.57	0.07	0.36	0.27	8.69
Miami	MDT	0.49	0.05	0.27	0.20	14.19
Houston	Metro	0.57	0.00	0.00	0.14	12.41
Los Angeles	LACMTA	0.21	0.08	0.23	0.07	8.33
Atlanta	MARTA	0.00	0.14	0.33	0.03	13.10
Dallas	DART	0.23	0.02	0.06	0.00	11.03

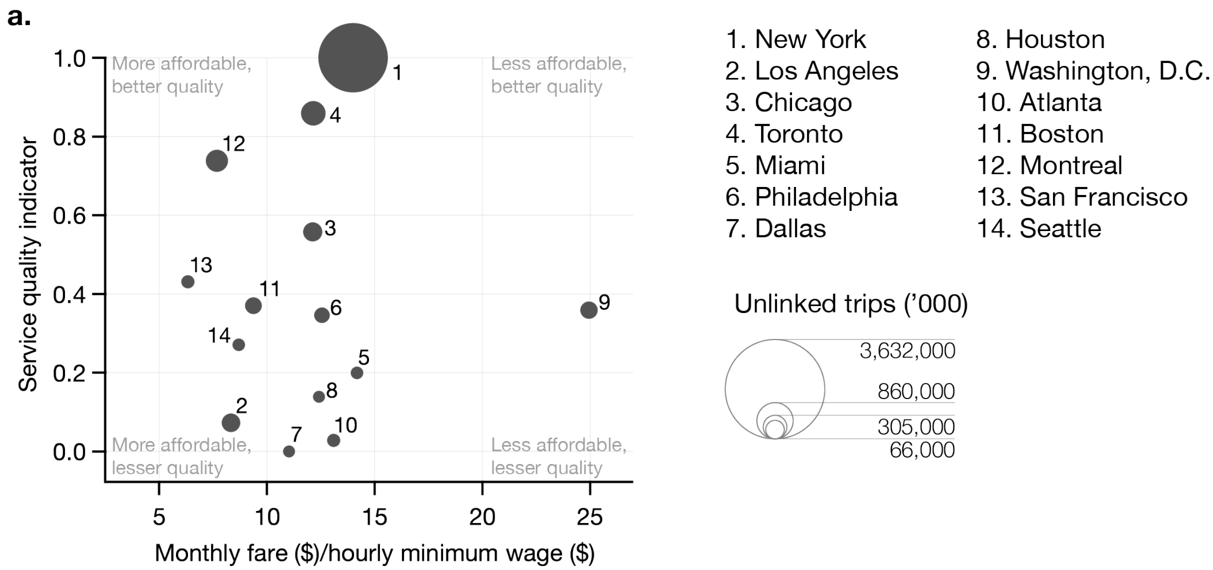

Figure 3.4. Service quality indicator plotted against a measure of affordability.

3.5 CONCLUSIONS

In this assessment, we distilled the qualities desired by transit riders, society, and transit operators into simple and easily obtainable indicators to assess the quality and affordability of transit agencies in large North American cities. We discovered that generally, agencies that offer quality service are expensive for minimum wage earners, while some of the lower overall performers are generally less expensive, while some poor performers are actually quite expensive. Nevertheless, two exceptions stand out, the STM in Montreal and the SFMTA in San Francisco, that are able to provide good service that is the most affordable in the cohort analyzed here.

Our study does have limitations and our indicators caveats. One limitation is the use of data from a single year, rather than studying potential changes in service quality over time. Indeed, in 2015, Metro in Houston reviewed its bus network and is now running new bus routes with greater frequencies (TransitCenter, 2016). Therefore, using the indicators developed here, Houston's ranking could change depending on whether the service adjustments and routes improve the 'headway' and 'accessibility' indicators. Therefore, our indicators are highly relevant in this context, and cases like Houston's highlight the need to study changes in quality (and affordability) over time. Moreover, our indicators are simplifications meant to address the qualities of public transport important to riders, society, and agencies. Unfortunately, metrics like reliability, travel time, on-board comfort, and the use of information technologies, go unreported or are non-standard across the industry. Take, for example, 'reliability', which is defined by different agencies as on-time performance, excess wait time, or headway adherence, among others (TCRP, 2013; Trompet, Liu, & Graham, 2011). Clearly, standardization and reporting can help in future assessments of transit quality. Moreover, choosing different indicators may result in a different ranking.

Using hourly minimum wage and the cost of an unlimited monthly fare, we devised a simple metric aimed at capturing the amount of work hours necessary to afford a monthly fare. Previous work has used single fares to estimate affordability, because apparently, this fare is the most accessible to low-income individuals (Carruthers et al., 2005). Without knowing the total salary of individuals earning minimum wage, it is hard to gauge what is an acceptable number of hours devoted to earning a transit fare. Nevertheless, transit fares are a chief concern of the working poor (Carruthers et al., 2005), particularly given the low minimum wages in many American cities. In some cities, such as Seattle and San Francisco, additional financial subsidies are available to low-income earners and may be a suitable strategy for improving public transport affordability (Stolper & Rankin, 2016), as well as subsidies offered through employers.

This paper aimed to provide a framework for assessing transit agencies and their affordability based on publicly available data. With this framework, researchers and planners can evaluate and locate areas of weakness or strength, as well as determine whether quality service necessitates expense. In addition, with a clear methodology that can be easily adopted, any agency around the world can calculate similar indicators and benchmark against our current findings. Future studies could use a comparable methodology to evaluate changes over time to learn whether agencies are improving or worsening, and how these conditions may impact affordability and attractiveness of service. Furthermore, our primary focus was on qualities important to riders like affordability, accessibility, service frequency, and comfort; however, not all riders value these qualities to the same extent. For instance, transit-dependent or captive riders are influenced less by comfort (Krizek & El-Geneidy, 2007), but affordability can be a major concern (Stolper & Rankin, 2016). Therefore, using customer surveys can help weight and identify indicators relevant to particular rider segments when composing a composite indicator.

CHAPTER 4. AFTERWORD AND CONCLUSIONS

Public transit can only benefit those who are able to access it—physically and financially. While previous research has investigated the social justice implications of spatial access to public transit and the destinations they serve (El-Geneidy et al., 2015; Geurs et al., 2009; Manaugh et al., 2015), there is a dearth of knowledge regarding equity and transit fares and affordability (Serebrisky et al., 2009). In this project, I studied how income predicts transit fare purchases, as well as the relation between affordability and the quality of public transit.

Using fare purchase records from metro station vendors and local neighbourhood vendors, I modelled monthly, weekly, and multiple weekly fare sales to determine the dependence of each on sociodemographic and built environment characteristics of the surrounding neighbourhood. Essentially, I discovered that increases in neighbourhood income would be expected to decrease the sales of multiple weekly fares at vendors; put another way, in neighbourhoods with low median incomes, vendors are expected to sell more multiple weekly fares than vendors in neighbourhoods with high median incomes. Moreover, this effect was independent of the percentage of part-time workers in a neighbourhood. Taken together, these findings suggest that in marginalized neighbourhoods in Montreal, some low-income earners may purchase multiple weekly fares to compensate for the large upfront cost of a monthly fare. This finding echoes observational findings in New York (Hickey et al., 2010). Therefore, our work highlights the need for transit agencies to ensure that their fare schemes are not unintentionally harming low-income earners who may spend more money over the course of a month by purchasing multiple weekly fares. Indeed, some transit agencies, such as those in Calgary, San Francisco, and Seattle, offer subsidies, vouchers or reduced fares to low-income riders (SFMTA, n.d.; King County Transit, 2015; Calgary Transit, 2015). Since the STM already uses fare smartcards, the STM could enroll qualifying low-income individuals to be directly eligible for reduced fares. If low-income individuals cannot afford the upfront price a monthly fare, having a fare-capping mechanism can permit paying-per-ride without penalizing riders who cannot buy an expensive fare at one time (TfL, n.d.). Future work should survey residents throughout Montreal to enquire into transit fare purchasing behaviour to directly validate our modelling results.

In the third chapter, I investigated affordability of public transit, which considered not only the monetary cost of a transit fare, but its relation to the hours of minimum wage work required to purchase a monthly fare. Indeed, a recent report of the working poor in New York found that the chief concern of this group was affordability of transit fares, over and above concerns regarding reliability and comfort of the subway (Stolper & Rankin, 2016). By this affordability indicator alone, compared to other agencies in large North American cities, a monthly fare in Montreal was the second most affordable, requiring nearly eight hours of minimum wage work. Moreover, a combined service quality indicator that accounted for attributes important to riders, society at large, and transit agencies themselves, resulted in the STM placing third, behind transit agencies in New York and Toronto. Overall, it does seem that more expensive agencies provide better quality service, and some expensive agencies provide lesser quality service as well. The methodology provided in Chapter 3 lays the groundwork for researchers and practitioners wishing to benchmark and compare transit agencies using simple indicators calculated with publicly reported data, and calls for industry standardization of metrics for reliability and amenities for customers, like next-arrival information. Nevertheless, future studies can refine the indicators used here, consider different perspectives, or consider weighting indicators based on rider preference surveys (Stolper & Rankin, 2016).

A critical reappraisal of transit fare structure is needed in many cities. Raising transit fares for individuals who can afford to pay more while lowering fares or offering subsidizes for vulnerable individuals may help address not only equity concerns, but also address funding shortages and improve transit quality for all (Aggarwala, 2012).

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