Riding LRT or taking the Bus? Examining Variation in Social Equity within the Transit Market across a City Geography (#17-04992)

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ABSTRACT

Choice and captive riders represent the two conceptual extremes of transit market demand, with agencies expected to provide services to both. Transit providers attempt to balance the needs of choice light rail transit (LRT) patrons with captive bus riders. Scholars agree that LRT and buses, however, serve different markets; compared to rubber-based services social equity benefits are lower for rail-based systems. This paper investigates social equity impacts on bus patrons in relation to LRT riders by examining mode-specific variation using four concentric rings of development that capture central city through suburban demand. Relying on an on-board rider survey from Edmonton, Canada, the analysis focuses on the decision to start a trip on transit, whether on bus or LRT, and jointly models the trip-start location using a mixed logit specification. The models indicate that, compared to LRT patrons, social equity increases for senior/youth bus riders, traveling in the morning peak, and walking to/from transit. The analysis suggests that social equity of riders is better served by improving bus over LRT services, particularly in the second and third development rings.

Keywords: Bus; Light Rail Transit (LRT); Mixed logit; Social equity; Transit demand

1. INTRODUCTION

A framework of egalitarianism (i.e., society ought to treat everyone equally) and sufficientarianism (i.e., society should make it possible for everyone to have minimum basic needs fulfilled) is objectively better when evaluating the social outcomes of transportation decisions by demographic group, geographic area, or time period (*1*). Research on transit has shown, however, that North American cities have been gradually moving away from the social-equity contract for supplying transit—instead providing services for choice riders (*2*). Researchers cite a variety of reasons that have led to this trend in transit investments including the growth of suburbs and service adjustments to maximize geographic coverage (*3*). Other investigators discuss a lack of community and political support for social justice issues (*4*), and the wealthier population's willingness to vote for transit without the disposition to ride transit (*5*). There is also a greater focus among voters and policymakers on congestion mitigation and local environment issues than on social equity goals; when such goals exist as policy they are not effectively translated into objectives (*6*).

The erosion of federal tax dollars to subsidize transit, greater reliance on funding from local sources, and the competition transit faces from other local public services during budgetary deliberations incentivize transit providers to focus on money-making routes and services. Transit agencies are funded, progressively, by choice voters who face weak behavioral nudges from gasoline pricing or parking fees to move from driving to transit. But providing for choice riders is a risky strategy in the long run since a system without riders cannot be successful (*2*, *5*).

1.1 Rail Versus Bus Riders

In this milieu of higher spending for choice riders, many North American agencies are motivated to invest in rail over bus transit, partly basing decisions on models that do not make accurate predictions over long horizons (*7*). Investing in long-life infrastructure using uncertain information is alarming given the low likelihood of growth in ridership. Taylor and Morris (*2*) show that rail-based transit caters to well-off riders, yet per passenger subsidy for an unlinked trip—in inflation-adjusted terms—has consistently been higher for rail rather than bus riders since 1995 in the US. Zhang (*8*) reports that operating costs for light rail transit (LRT) on a per revenue mile or per revenue hour basis is three-fold the cost of running buses in the US. An argument can be made that transit policy for cities needs to be a function of diverse needs; ideally a variety of taste preferences can be served by an array of transit services (*8*, *9*). This paper asks specifically: given limited funding, where should transit's *social equity* priorities lie?

Many investigators have found that choice riders are well-off consumers of specialized rail or premium bus services, while captive patrons are likely to be low-income and disenfranchised groups (e.g., *9*, *10*). Rail transit patrons are often downtown commuters who are at least as well-off as those traveling by private automobiles, and the difference in income between rail and bus travelers is growing (*2*). Perceptions of transit and satisfaction are different between these groups, with captive riders expressing dissatisfaction yet riding transit (*10*).

Researchers have also commented on the modal preference for LRT over buses (*11*), and about the lack of bus-rapid transit (BRT) as a realistic transportation option in the developed world (*8*). This bias against rubber-based transit is rooted in image (*12*), though stated-preference research reveals that considerations of capital cost, geographic spread for given capital spent, and dedicated lane attributes make BRT favorable (*13*). Other characteristics that make transit generally—and buses specifically—less favorable are long wait times, system unreliability, crowding, more transfers, and modal technology (BRT versus bus) (*11*, *14*). Yet investing in a specific transit technology—e.g., LRT over BRT—impacts ridership only to an extent. Unless concomitant policies for land use (e.g., density, diversity, design) and transportation (e.g., fuel and parking pricing) are in place, ridership is not likely to grow.

1.2 Research Agenda: Capturing Variation in Utility by Geography

The nature of demand is different for each transit system due to local peculiarities. These differences are driven as much by land use policies and employment agglomeration, as by the political economy of the locale (*4*). Developing further the arguments in Jaroszynski et al. (*3*) and Brown et al. (*9*), this paper employs a discrete choice methodology to examine revealed social equity variation between LRT and bus riders for a case where land uses are similar to job and housing distributions commonly seen in North American cities. The case discussed in this paper—Edmonton, Canada—has a central core and first ring post-war development, a few job centers, and sprawling suburban growth in concentric outer rings.

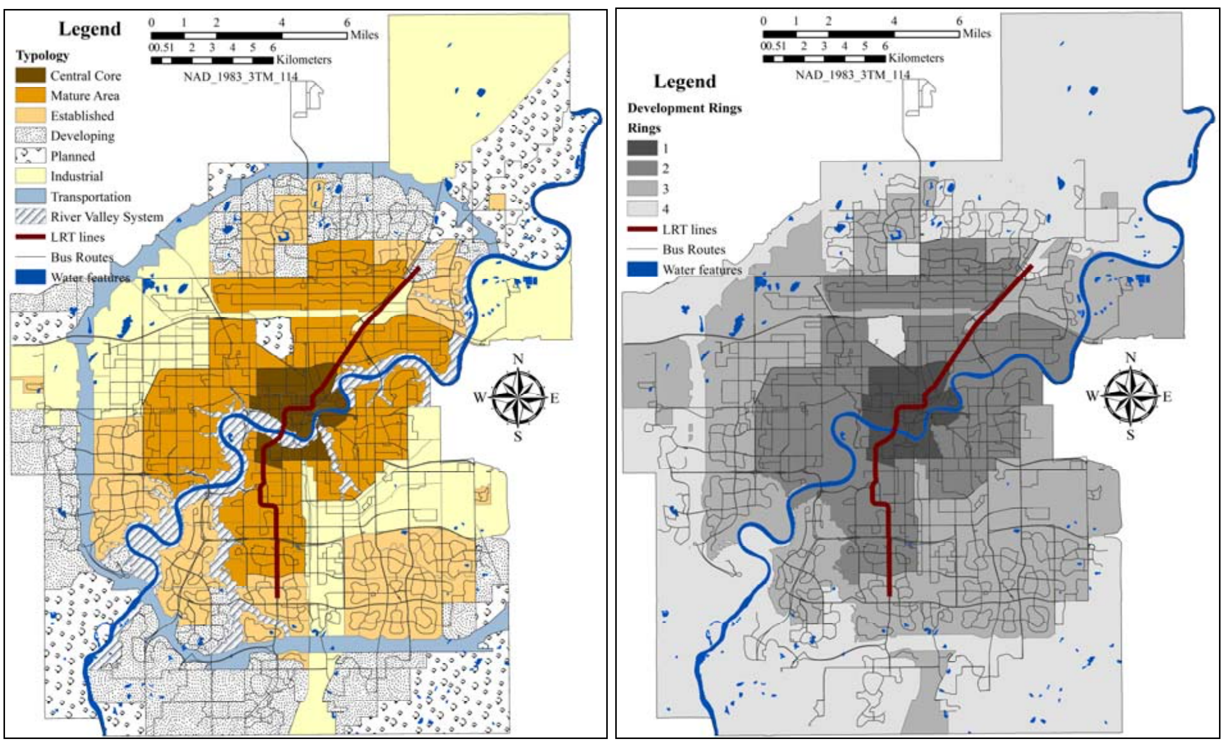
There is limited social-equity research looking at agent-level decisions i.e., how do individual patrons reveal preferences about transit systems? Disaggregate sources, including on-board surveys or more recently smartcard data, contain spatial information. With these location attributes and linked socio-economic characteristics of trip makers, it is relatively straightforward to examine revealed utility by transit mode and geography. The objective of this paper is along these lines, where the central hypothesis is that bus services, over LRT provision, increase utility for certain demographic groups. Since the intention is to measure social equity of the transit system, the decision to start a trip on bus or LRT is the unit of analysis. Total demand on the transit system is, hence, included in the modelling effort. This paper asks the following interlinked research questions: (i) How can disaggregate ridership data reveal utility gained by patrons on a multi-modal transit system? (ii) How can variation in utility on transit across the geography of a city be measured and compared? The paper employs logit model specifications and on-board rider survey data collected in the City of Edmonton, Canada to answer these questions.

2. MOTIVATION

Edmonton's population was about 880,000 in 2014, which is the year the on-board rider survey used in this paper was conducted. During the 2014 Municipal Census, of those who reported mode of travel to work, 70% drove, 6% were passengers, 16% used transit, 4% walked, 3% used other modes, and 1% bicycled (*15*). Edmonton Transit System (ETS) is the transit agency for the City of Edmonton, and is responsible for LRT, bus, and paratransit services. ETS' vehicle fleet, in 2014, comprised 1,049 buses and 94 rail vehicles, plying on 208 routes. The average weekday ridership was 404,500 and the annual operating budget was CAN$ 323 million (*16*). ETS is chartered with providing subsidized services for various demographic groups, namely, seniors ($\geq$ 65 years), youth ($\leq$ 18 years), the disabled, students in public/catholic schools, and university students. These subsides are offered as monthly, semester, or annual passes (*17*). ETS also provides a 24% subsidy to local businesses to encourage their employees to use transit through the *ETS@Work* program.

City Council's formal transit policy (*18*) stipulates that a transit service should be available no more than 800 meters from every address during operating hours; 400 meters in residential areas and 600 meters in employment areas during peak hours. A peak period service is offered for a population threshold of 500 persons in newly developed areas, with a stipulation that these services be maintained for at least a year. The *Transportation Master Plan* for Edmonton (*19*) discusses a few broad goals with regard to transit. LRT expansion is a cornerstone objective within public transportation, with a joint focus on integrated bus, premium bus, and paratransit services. The Plan discusses the need for land use policies to encourage compact urban development. In terms of transportation infrastructure supply, between 2006 and 2015, the road network grew by 3.5% across the city, with 8.7% growth in the outmost ring (author's calculations). LRT has also seen gradual extension in the recent past, with further multiple routes approved by City Council, some extending into rings 3 and 4 (*20*).

Figure 1a shows neighborhood typology in Edmonton, as used by the city in planning deliberation and policymaking. Focusing on the prominence of the central city as a key destination (*21*), and aggregating some types of neighborhoods into larger groups, four concentric rings are assembled to depict urban growth (Figure 1b) (*22*). Zahabi et al. (*23*) use cluster analysis of land use and bus supply attributes to classify neighborhoods; they find classes that are similar in character.



(a) (b)

FIGURE 1 (a) Neighborhood typology (b) Development rings. Edmonton, Canada (March 2014).

Edmonton represents a city wanting to provide a diverse set of alternatives for travel. A variety of options including legacy LRT, street/urban LRT, premium bus routes, feeder buses, and regular services can arguably serve most needs and taste preferences. Should suburbanizing cities with large populations that drive alone, however, prioritize capital-intensive rail investments? This paper argues that given limited funding and a push towards direct-democracy models for decision making, it is unlikely that transit's social equity rationale can be fulfilled through rail investments.

3. RECENT RESEARCH PROGRESS

This review focuses on recent developments in transit research. Four categories are used in this paper to highlight various aspects of the recent literature upon which the analysis for this paper is based. The first category of choice and captive riders is used as an overall frame for this paper.

Accessibility by Transit: Levine et al. (*24*) show that accessibility gains are higher when land uses are dense with closer origin-destination pairs, relative to when travel speeds are faster through system improvements including supplying greater road capacity. Merlin (*25*), however, shows that the transit accessibility benefits from speed gains are different based on the case; though largely positive in three of four cases analyzed, suburban growth in housing negatively impacts regional accessibility.

Bus riders gain job accessibility with a network of bus routes that have better connectivity to various employment centers—not just CBD locations, while rail riders seek faster services to employment locations within walking distance (*9*). Some researchers show that job accessibility increases in areas close to LRT stations and along direct feeder bus routes. Similar gains are limited for areas with regular bus services, with low-wage employees benefiting less from LRT (*26*). Others find that transit investments over a 10-year horizon improve accessibility for the socially disadvantaged (*27*), yet these impacts are largely negative for low-wage workers in cross-sectional analysis for the same location (*28*). Transit demand does not go up over time accounting for investments but highway investments bring down transit mode shares for all job types (*29*).

Location Self-selection: Households have preferences that they reveal by making choices regarding where to live and—to a lesser extent—where to work. This location self-selection bias can influence travel mode choice (*30*) and lends itself to classifying a city into zones, either as buffers (*31*) or concentric rings (*22*). Research suggests that the impact of transit supply is evident in housing decisions, with likely choice riders self-selecting to move to areas near light rail corridors (*32*, *33*, *34*). Without affordable housing policies, however, dependent and captive riders are often removed from these catchment areas around stations (*35*). Research also indicates that LRT investments catalyze behaviors towards transit use and reduction in driving rates for households (*31*). It is unclear, however, if those who choose to move to transit rich areas ride transit any more than others in comparable corridors; particularly the tendency to reduce car ownership seems not to change (*32*).

Mixed Models: Researchers have adopted mixed logit modeling techniques to study travel behavior, with a focus on location choice and travel decisions of users (e.g., *22*, *36*). Cao and Ettema (*33*) use a different approach where they assume that respondents in a corridor may have similar unobserved attributes, so they specify a multilevel fixed effect model with dummies for each corridor in the sample. Næss (*21*) specifies a model with both macro and micro geography variables and finds that city level variables exert stronger impacts on the choice to drive a car than neighborhood-level variables. Zahabi et al. (*23*) simultaneously model mode choice and residential location for commuters in rail proximate areas, classifying neighborhoods into four types and modes into private and public transit choices.

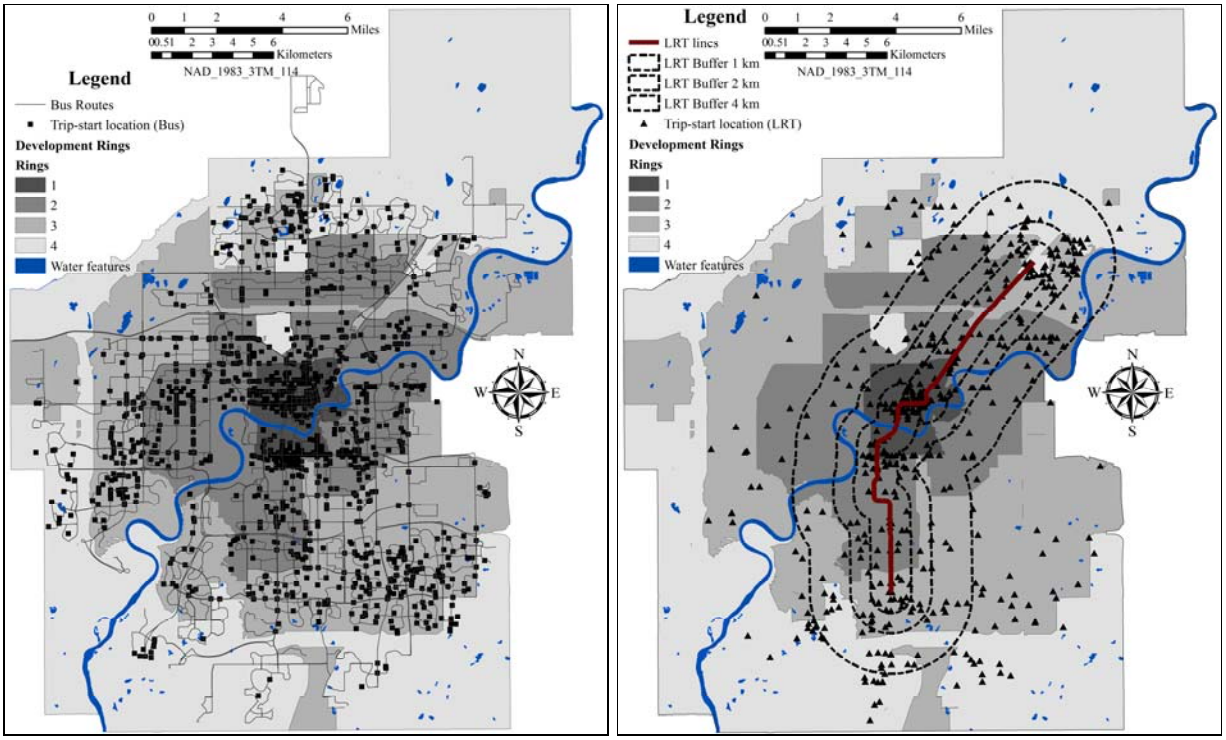
This review shows that it is unclear whether accessibility improves for the socially disadvantaged over time with transit investments (especially LRT). Recent research suggests that the accessibility impacts of transit investments are tied to the agglomeration of jobs and relative location of housing, with low-wage employees having the least to gain from premium transit investments. Researchers largely agree that location self-selection has an impact on mode choice, with those living in an area that has new rail investments being nudged into transit use and reduced driving. It is unclear if choice riders who move into transit rich corridors have similar mode shifting tendencies over the long term.

Many researchers in North America have focused on analyzing social-equity on transit, relying largely on census-based measures or other aggregate data from system attributes and nation-wide polls. This vigorous body of scholarship is foundational for the next stage of social-equity analysis presented in this paper, where the contribution is to demonstrate how discrete choice modeling methods capture taste heterogeneity in agent-based decisions not just by transit mode but also by urban geography. A specific gap in the literature is regarding the effects of location self-selection for trips on different transit modes. For example, Zahabi et al. (*23*) group commuter rail, metro, and bus together because it serves their research question. In this paper, the two available transit modes—light rail and bus—are compared to investigate social equity outcomes.

4. DATA AND ANALYTICAL APPROACH

The on-board ridership data for this investigation comes from the City of Edmonton. The survey was in the field between the 3rd and the 11th March, 2014, with the first seven days focused on bus riders and last two days on LRT patrons. The sampling strategy was based on automatic passenger counter (APC) data, with distribution across routes being statistically representative of actual demand from cumulative ridership. A total 10,636 surveys were distributed (76% on bus and 24% on LRT), of which 7,306 (69%) were returned. Of these responses, 3,754 (51%) had indicated a trip-start location at a high enough accuracy to confidently geo-code it to a specific neighborhood.

LRT riders were unfortunately not surveyed over the weekend; hence weekend bus trips were removed for accuracy of comparison between the two subsets of transit patrons. Some respondents within this subset had other minor missing information for covariates used in the models for this paper, reducing the number of records to 2,411 (66% on bus and 34% on LRT) (Table 1). There is confidence that the final subset of responses included in the models is fairly representative of the ridership on the Edmonton Transit System across modes and geography (Figure 2). Two drawbacks, however, need to be kept in mind when interpreting the results: (i) linked trips were not captured in the survey, hence the analysis is limited to unlinked trips as the unit of analysis, and (ii) standard socio-economic variables namely gender, education, and income were not included on the survey.



(a) (b)

FIGURE 2 Trip starts by mode (a) Bus routes and bus trip starts (b) LRT routes and LRT trip starts.

Figure 2a shows bus routes in 2014 along with trip-starts from the survey, while figure 2b shows the same for LRT. Trip starts on both transit modes are spread across the city's geography, though the outermost ring has relatively few trip starts as expected (Table 1). Given the limitations of the dataset, the focus is on measuring utility as a function of individual decisions to start a trip on transit. (Mixed models with trip-end data were estimated but proved unstable). Creating area buffers to capture and portray demand on transit is a technique often utilized by scholars (e.g., *31*), the argument being that those closer to transit (especially LRT) self-select to locate there and are likely to be more transit-oriented. This paper uses a different approach by considering that every trip start on a transit mode in a certain development ring is similar in some unobserved way to every other trip start in the same ring on that transit mode—e.g., rider's political beliefs or preference for a front lawn may be similar.

Researchers have generally relied on finer scale geographies (e.g., census tracts or traffic analysis zones) to study social equity impacts of transit investments. These geographic units of analysis are indeed useful in making decisions for transit systems. This paper uses four rings of development across the city since this enables the findings to be interpretable for city-wide investment policy (Figure 1b). There is a loss of granularity in using development rings, which is a necessary sacrifice given the research agenda of comparing bus and LRT riders across the system. Potential self-selection is controlled by including larger zones, i.e., development rings, where patrons with certain taste preferences are likely to travel from—e.g., downtown employees who are suburban choice riders driving to LRT stations or millennials living and going to university in the central core. Finally, given the lack of income information in the dataset, mode choice taste variation is also better captured by using geographic units where particular housing and destination choices agglomerate.

Table 1 Overview of Variables Used in the Analysis

Dependent variable for binomial logit model of transit mode choice				
			Observations	*% of Sample*
LRT trip starts (reference category)			819	34.0%
Bus trip starts			1592	66.0%
Dependent variable for mixed logit model of joint decision of trip start location and transit mode choice				
Development Ring	*LRT trip-start*	*Bus trip-start*	*Observations*	*% of Sample*
1 (Central Core) (reference category)	Yes	No	396	16.4%
1 (Central Core)	No	Yes	461	19.1%
2 (Second Ring)	Yes	No	180	7.5%
2 (Second Ring)	No	Yes	576	23.9%
3 (Third Ring)	Yes	No	154	6.4%
3 (Third Ring)	No	Yes	461	19.1%
4 (Fourth Ring)	Yes	No	89	3.7%
4 (Fourth Ring)	No	Yes	94	3.9%
Total observations in modeling frame			2411	
Dummy variables (from on-board survey data)				
		Mode	*Observations*	*% of sample*
Senior (≥ 65 years) or youth (≤ 18 years)		0	315	13.1%
Walked to transit (access mode)		1	2202	91.3%
Walked from transit (egress mode)		1	2282	94.6%
Trip started and ended in the AM peak (between start of service and 9:00 a.m.)		0	587	24.3%
Paid for trip with discount fare (senior pass, university pass, youth pass, transit subsidy program for physically challenged, or employer transit subsidy program)		0	662	27.5%
Continuous variables at neighborhood level (from Municipal Census 2014 and land use data)				
	Mean	*Std. Dev.*	*Minimum*	*Maximum*
Percentage of households reporting length of residence in dwelling unit as 5 years or more (from Municipal Census 2014)	0.24	0.19	0	0.82
Sum of the assessed value of commercial properties less than 1 million CAN$ (Million CAN$)	28.8	41.8	0	127.3
Population density (persons/km^2)	3252	2484	0	11993
Number of social services available	5.0	10.1	0	30.0
Growth in street length (total streets in 2015 minus total streets in 2006) (km)	3.6	3.1	0	29.0

Note: Some continuous variables entered the model transformed but are reported here in their original form.

Table 1 presents an overview of variables used in the analysis for the logit models. For the mixed logit, the choice set is comprised of eight options, where a trip can begin in any of the four concentric development rings (Figure 1b) and jointly on either bus *or* LRT. The distribution of the eight options shows that bus trip-starts are high in all but ring 4. LRT trip starts are highest in ring 1, diminishing sharply in ring 2 and outward. Two forms of covariates are included in this analysis; a set of dummy variables from the on-board survey and a linked set of attributes at the neighborhood level from the 2014 Edmonton Municipal Census and land use data.

5. MODEL SPECIFICATION

This study's objective is to reveal the social equity outcomes of transit services (*1*, *6*). The study relies on the decision to start a trip on transit, throughout the day and for all trip purposes. This investigation, thus, captures a full demand profile on the transit services for an average five-day workweek. Given the research method employed, the data reveals comparative utility rather than assuming *a priori* that rail is utility generating and bus is utility diminishing. The paper uses a binomial logit model to compare bus and LRT riders, and a mixed logit model that jointly estimates location of trip starts and transit mode.

Among the various mode choice models in the transit literature, binomial logit is often employed (e.g., *30*). A binomial logit model is specified for this paper to explore social equity impacts across the two transit modes controlling for a rich group of predictors, especially neighborhood-level covariates where trips start and end (Table 2). Simultaneous modeling of choices for location and travel decisions, using some form of a mixed multinomial logit specification, has also been employed by researchers (e.g., *22*, *36*). A mixed logit specification is used to estimate outcomes for the binary choice of bus or LRT with the multinomial choice of trip-start location in one of the four development rings (Table 3) (*23*). For a detailed discussion of model specification see Train (*37*). The estimated utility of the eight choice alternatives is given by:

$$U_{ij} = \alpha_j + \beta X_{ij} + \chi Y_{ij} + \gamma_{ijm} + \delta_{ijr} + \varepsilon_{ij}$$

where,

– Subscripts *i*,*j*,*m*, and *r* respectively represent individual unlinked trip-starts, choices (one of eight – Table 1), transit modes (bus or LRT), and development rings.
– α_j are alternative specific constants for the choices (LRT trip-starts in central core is the reference alternative).
– βX_{ij} is the vector of estimated parameters multiplied by the column vectors of socio-economic (senior or youth dummy) and trip attributes (morning peak trip and discount fare dummies).
– χY_{ij} is the vector of estimated parameters multiplied by the column vectors of neighborhood-level attributes (social services available at trip end and growth in street length at trip start).
– γ_{ijm} are zero-centered, normally distributed random error components for transit modes.
– δ_{ijr} are zero-centered, normally distributed random error components for the development rings.
– ε_{ij} is type-1 Gumbel-distributed random error term.

The random error components are simulated with quasi-random Halton draws using the software Biogeme (*38*). Estimation was tried with 500 through 2500 Halton draws; the coefficient signs and values were similar over the range.

6. DISCUSSION OF FINDINGS

6.1 Binomial Logit Model of Transit Mode Choice

The binomial model shows that the likelihood of seniors ($\geq$ 65 years) or youth ($\leq$ 18 years) using bus transit is 2.5 times higher than LRT use, holding all else constant. If a patron accesses transit by walking, she is 3.0 times more likely to use a bus service rather than ride on LRT. If a transit rider similarly walks to her final destination, she is 4.5 times more likely to have been on a bus, all else being equal. These findings for access and egress by walking make intuitive sense since bus routes and bus stops are more widely spread through neighborhoods. If a transit patron begins and ends her transit trip during the morning peak—Edmonton's official morning peak for transit services is between start of service and 9 a.m.—she is 4.5 times more likely to be on a bus rather on LRT, all else being equal. If a rider pays for transit, however, using a discount fare (see Table 1 for definition), she is 44% *less* likely to be on a bus compared to being on LRT. A likely explanation for this effect is that many regular discount fare patrons in Edmonton are high school/university students or employees in firms located in the central core, where LRT stations are conveniently located, shifting preference away from bus use.

For every percentage point increase in households that report living 5 years or more in a neighborhood where a trip started, the likelihood of a transit trip on bus goes up by 4.5 times compared to LRT—this likelihood is 12.5 times greater at the trip-end neighborhood locations. This suggests that in neighborhoods where housing tenure is long (≥ 5 years), demand is higher for bus compared to LRT. It is possible that neighborhoods with a greater percentage of well-off households with long tenure may be biased towards LRT use. Using assessed value of residential properties as a proxy covariate to test this conjecture proved inconclusive however, since t-tests failed by a wide margin. If, however, the total value of commercial properties assessed at less than a million CAN$ goes up in a neighborhood cumulatively by 10 million CAN$, likelihood of bus use goes up by 15% at both the trip-start and trip-end locations, holding all else constant. This finding suggests that finer-grain commercial development generates demand on bus transit, which makes intuitive sense.

TABLE 2 Binomial Logit Model of Transit Mode Choice

(Reference category – LRT)	*Parameter*	*Robust Std. Err.*	*Robust t-test*	*Exp. value of parameter*
Categorical/Dummy covariates (from on-board survey data)				
Senior (≥ 65 years) or youth (≤ 18 years)	**0.86**	0.19	4.48	2.35
Walked to transit (access mode)	**1.12**	0.19	5.94	3.06
Walked from transit (egress mode)	**1.53**	0.28	5.55	4.62
Trip started and ended in the AM peak	**1.54**	0.15	10.03	4.66
Paid for trip with discount fare	**-0.58**	0.12	-4.93	0.56
Continuous covariates at neighborhood level (from municipal census 2014 and land use dataset)				
At neighborhood location of trip start				
Percentage of households reporting length of residence in dwelling unit as 5 years or more	**1.53**	0.42	3.67	4.62
Sum of the assessed value of commercial properties less than 1 million CAN$ (10 Million CAN$) (‘0)	**0.14**	0.03	4.01	1.15
Population density (persons/km^2) (‘000)	-0.03	0.04	-0.89	0.97
Growth in street length (total streets 2015 minus total streets 2006) (km)	**-0.05**	0.02	-2.94	0.95
Number of social services available [LN (value + 1)]	**-0.68**	0.11	-6.33	0.51
At neighborhood location of trip end				
Percentage of households reporting length of residence in dwelling unit as 5 years or more	**2.51**	0.42	6.00	12.30
Sum of the assessed value of commercial properties less than 1 million CAN$ (10 Million CAN$) (‘0)	**0.15**	0.04	4.07	1.16
Population density (persons/km^2) (‘000)	**-0.21**	0.04	-5.47	0.81
Growth in street length (total streets 2015 minus total streets 2006) (km)	**-0.09**	0.02	-4.45	0.91
Number of social services available [LN (value + 1)]	**-0.67**	0.11	-5.88	0.51
Constant	-1.27	0.36	-3.51	
Summary Statistics				
Null log-likelihood	-1643.45			
Final log-likelihood	-1206.49			
Likelihood ratio test	873.93			
Adjusted rho-square	0.26			

Note: Bolded values are significant at 95% (i.e., t-statistic ≥ 1.96).

For every 1,000 persons/km^2 increase in density at the trip-end neighborhood location, the likelihood of bus transit use goes down by 19%. This finding suggests that higher population agglomeration is conducive for BRT/LRT investments or that in higher density locations other options for travel including taxis, Transportation Network Company (TNC) services (Uber), etc. exist. For every kilometer of growth in the street network between 2006 and 2015 in a neighborhood, the likelihood of bus use relative to LRT decreases by 5% at trip-start locations, all else being equal—this effect is 9% at trip-end locations. Growth in street length likely induces higher traffic and congestion, thus reducing bus transit demand at the margin. For every 2.7 times increase in social services in a neighborhood, the likelihood of bus use goes down by 49% at both the trip-start and trip-end locations, all else being equal. Many social services in Edmonton are concentrated in the central core, where LRT services are also plentiful, which likely reduces attraction for bus use to access social services. This suggests, however, that in cities with a dispersion of social service destinations across the geography, bus transit can be important.

6.2 Mixed Logit Model of Joint Decision of Trip Start Location and Transit Mode Choice

The mixed logit shows parameter estimates for the joint decision of where to start a trip on transit and by which mode, bus or LRT. This model specification reveals nuanced impacts for bus and LRT riders who start trips in the four rings; impacts that are not evident in the binomial logit model. Since the random error components are insignificant, there is confidence that the included explanatory variables perform well in encapsulating homogenous taste preferences within the eight choices.

Transit users who are seniors (≥ 65 years) or youth (≤ 18 years) gain utility overall, but compared to utility gains in LRT trips, bus trip makers have higher utility. The model shows that utility is highest in rings 2 and 3 for both the modes, indicating that age-based social equity policies can be a function of where patrons in these categories start trips—this is in the middle development rings for Edmonton. Trips on transit that start and end in the morning peak are overall utility gaining for the patrons in the sample. AM peak bus riders, however, gain much more utility than those on LRT in every development ring. Utility for bus riders during morning travel increases rapidly outward from the core; utility for LRT riders is highest in ring 3 albeit at a lower magnitude. Those who pay discounted fares on transit, however, lose utility overall, relative to patrons riding LRT from the central core. The parameter estimates indicate that, particularly in ring 3, utility loss is high for transit uses on discounted fares.

TABLE 3 Mixed Logit Model of Joint Decision of Trip Start Location and Transit Mode Choice

(Reference category – LRT trip starts in ring 1)	*Parameter*	*Robust Std. Err.*	*Robust t-test*	*Exp. value of parameter*
Senior (≥ 65 years) or youth (≤ 18 years) (Dummy)				
Bus trip starts in ring 1	**0.82**	0.42	1.96	2.27
Bus trip starts in ring 2	**2.63**	0.39	6.73	13.87
Bus trip starts in ring 3	**2.50**	0.65	3.84	12.18
Bus trip starts in ring 4	**1.69**	0.52	3.24	5.42
LRT trip starts in ring 2	**1.47**	0.46	3.23	4.35
LRT trip starts in ring 3	**1.56**	0.73	2.13	4.76
LRT trip starts in ring 4	**1.36**	0.58	2.34	3.90
Trip started and ended in the AM peak (Dummy)				
Bus trip starts in ring 1	**2.19**	0.33	6.68	8.94
Bus trip starts in ring 2	**2.58**	0.34	7.51	13.20
Bus trip starts in ring 3	**2.73**	0.52	5.24	15.33
Bus trip starts in ring 4	**3.02**	0.40	7.54	20.49
LRT trip starts in ring 2	0.74	0.41	1.81	2.10
LRT trip starts in ring 3	**1.78**	0.56	3.19	5.93
LRT trip starts in ring 4	**1.60**	0.44	3.66	4.95
Paid for trip with discount fare (Dummy)				
Bus trip starts in ring 1	**-0.99**	0.15	-6.43	0.37
Bus trip starts in ring 2	**-1.02**	0.18	-5.59	0.36
Bus trip starts in ring 3	**-4.08**	1.59	-2.56	0.02
Bus trip starts in ring 4	**-1.32**	0.32	-4.10	0.27

LRT trip starts in ring 2	-0.21	0.22	-0.97	0.81
LRT trip starts in ring 3	**-3.25**	1.62	-2.00	0.04
LRT trip starts in ring 4	-0.43	0.25	-1.73	0.65
Growth in street length (total streets 2015 minus total streets 2006) (km) in neighborhood where trip starts				
Bus trip starts in ring 1	**-0.22**	0.04	-5.43	0.80
Bus trip starts in ring 2	**-0.82**	0.06	-12.78	0.44
Bus trip starts in ring 3	**-0.70**	0.20	-3.46	0.50
Bus trip starts in ring 4	**0.33**	0.05	6.73	1.40
LRT trip starts in ring 2	**-0.94**	0.07	-13.15	0.39
LRT trip starts in ring 3	**-0.76**	0.20	-3.89	0.47
LRT trip starts in ring 4	**0.31**	0.05	6.23	1.37
Number of social services available [LN (value + 1)] in neighborhood where trip ends				
Bus trip starts in ring 1	0.03	0.07	0.48	1.03
Bus trip starts in ring 2	0.04	0.08	0.52	1.04
Bus trip starts in ring 3	0.33	0.23	1.44	1.39
Bus trip starts in ring 4	0.11	0.13	0.83	1.11
LRT trip starts in ring 2	**0.34**	0.09	3.92	1.40
LRT trip starts in ring 3	**0.80**	0.23	3.42	2.23
LRT trip starts in ring 4	**0.62**	0.09	6.87	1.86
Random error components				
Bus	-0.02	0.07	-0.28	
LRT	-0.23	0.22	-1.06	
Ring 2	0.04	0.02	1.66	
Ring 3	5.74	3.11	1.85	
Ring 4	0.00	0.01	-0.23	
Alternative specific constants				
Bus trip starts in ring 1	1.21	0.21	5.82	
Bus trip starts in ring 2	2.88	0.27	10.61	
Bus trip starts in ring 3	0.16	1.27	0.13	
Bus trip starts in ring 4	-3.60	0.36	-9.98	
LRT trip starts in ring 2	2.04	0.29	7.01	
LRT trip starts in ring 3	-1.14	1.29	-0.89	
LRT trip starts in ring 4	-3.88	0.36	-10.82	
Summary Statistics				
Null log-likelihood	-5013.53			
Final log-likelihood	-3733.94			
Likelihood ratio test	2559.19			
Adjusted rho-square	0.25			
Number of Halton draws	2500			

Notes: Bolded values are significant at 95% (i.e., t-statistic ≥ 1.96).

The impact of growth in street length is different in the various development rings, with transit riders on both bus and LRT loosing comparable utility in rings 2 and 3. For bus riders this impact is likely from increased congestion, while for LRT patrons growth in street capacity can induce higher parking demand at stations. The models consistently show, however, that utility *grows* with increase of street length in ring 4 for both bus and LRT patrons comparably. A likely explanation of this change in sign for LRT riders is that greater street length enables quicker driving access to and egress from stations. For bus riders in the growing suburbs, this impact is likely from quicker bus trips resulting from more street capacity. With growth in social services, the mixed logit shows that utility increases for LRT patrons in rings 2 through 4—this effect is inconclusive for bus riders. Similar to the binomial logit model, the gains in utility from increase in social services at a neighborhood level may be linked to agglomeration of services in the central core of Edmonton with convenient LRT access.

7. POLICY IMPLICATIONS AND CONCLUDING REMARKS

The analytical innovation in this paper is to show that social equity studies related to transit systems that are based on rider's joint decisions—specifically where a trip starts and on which transit mode—are modeled effectively in a mixed framework. Using such a mixed discrete choice framework reveals more insights about gains and losses in utility than using unordered logit specifications. The city is divided into four concentric rings in this investigation making it possible to report the findings easily, and interpret them at a geography where policy makers can understand impacts of transit supply as a function of city growth.

The models indicate that, compared to LRT patrons, social equity increases for senior/youth bus riders, traveling in the morning peak, and walking to/from transit. A nuanced insight from this investigation is that cities need to consider transit supply in central core locations plus mature suburbs (developed 1945-1980s). Specific social equity policies indicated are subsidizing travel for youth and seniors in these sub-geographies. During the morning peak, in Edmonton, resource allocation can be aimed at bus transit all over the region and higher frequency for LRT from ring 3 inwards. Street supply in ring 4 increases utility for both LRT and bus services; these gains likely are from quicker trips to stations, transit hubs, as well as on buses. Cities should consider, however, the negative externalities from more street growth in suburbs. From an emissions perspective, given low ridership in suburbs and higher drive alone rates to access transit, a case can be made for smaller transit vehicles. Vans, shared use services/TNCs, and subsidized station parking for carpoolers can result in environmental gains.

As cities struggle with shrinking funding for transit, greater demands for LRT systems that serve choice riders, and calls for transit service to all geographies in an urban area, there is an urgent need to understand the social equity implications of transit investment decisions. Whether LRT should be extended out to newly developing suburbs remains a question for policy debate. In consensus with the larger transit literature the models in this paper show that LRT investments result in social equity gains in areas with higher agglomeration of destinations that have employment and/or institutional land uses. Regular bus services should, however, be the focus of transit agencies mandated to serve captive and dependent riders.

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