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If you build it, who will come? Exploring the effects of rapid transit on residential movements in Metro Vancouver

Bogdan Kapatsila
School of Urban and Regional
Planning, University of Alberta
kapatsil@ualberta.ca

Jordan D. Rea
School of Urban and Regional
Planning, University of Alberta
jrea@ualberta.ca

Emily Grisé
School of Urban and Regional
Planning, University of Alberta
egrise@ualberta.ca

Abstract: As cities across the world embrace the benefits of rapid transit technology and invest in the expansion of existing infrastructure or plan for the introduction of new lines, the differences in both benefits and externalities that bus rapid transit (BRT) and rail rapid transit (RRT) bring remain unclear. This study aimed to address that gap and understand whether there was a distinction in impacts on the residential migration of households in different income and residential tenure groups as the result of BRT and RRT projects. This was achieved by exploring the effects of both modes in the same metropolitan region—metro Vancouver. This study used three BRT and three RRT lines that were in service for all or part of the 20 years spanning 1996 through 2016 to assess the rates of in-movement of households by income in Census Tracts (CTs) within 800 meters (½-mile) of a given rapid line. Our analysis suggested that areas adjacent to the Expo-Millennium RRT Corridor saw fewer in-movers between the 2001 Census and the 2016 Census than the areas without rapid transit infrastructure, while the same was true for the CTs affected by BRT lines and that had a larger than average share of new housing while holding everything else (e.g., housing supply) constant. While we did not find evidence to state that the presence of rapid transit infrastructure disproportionately affected any one of the income groups, our analysis suggested that there were more affluent renters moving in along the RRT and BRT lines. At the same time, the share of low-income renters that moved into areas close to rapid transit lines remained relatively stable. This research added a unique perspective to the debate cities and transport agencies have been experiencing with respect to decisions around the investment into different transport technologies and contributed to the argument for the need to carefully plan and provide rapid transit infrastructure together with affordable and diverse housing options.

Keywords: Public transit, bus rapid transit, transit impact, residential choices, housing affordability

Introduction

Transport agencies are facing important decisions concerning the trade-offs between the capacity, upfront, and operational costs, as well as externalities of different transit technologies, namely bus rapid transit (BRT) and rail rapid transit (RRT), and how their benefits can be facilitated to achieve sustainability targets and reverse declining transit ridership trends (Boisjoly et al., 2018). While RRT is often viewed as inherently more attractive than bus systems, if designed well (e.g., with high frequency, dedicated right-of-way, platform-level boarding, etc.), BRT can be equally as attractive to rail (Ben-Akiva & Morikawa, 2002). Several benefits can be accrued by opting for a bus rather than a rail-based system. Namely, these include lower costs, quicker construction timelines, and additional flexibility to modify routing, but with lower projected ridership based on the expected demand generation of BRT relative to RRT (Cervero, 2013; Metrolinx & IBI Group, 2013). There is clear evidence that rail-based projects positively impact land values and more likely lead to gentrification (Grube-Cavers & Patterson, 2014; Jones & Ley, 2016; Topalovic et al., 2012). At the same time, no clear empirical evidence exists regarding the socioeconomic impacts of BRT development in Canada—a gap our research aims to fill. It is important for the socioeconomic impacts of transport technology choices to be considered as they can adversely disrupt the social fabric of communities in the process of providing a community benefit, and this knowledge to inform the development of better planning practices.

Moreover, as far as we know, no study has explored the effects of bus and rail rapid transit simultaneously in the same metropolitan region; this allows for an investigation into the different effects arising from different modes while controlling for inherently different regions and macro-level planning and transport policy differences. Therefore, using Metro Vancouver, British Columbia, Canada as a case study, we investigate the residential movement of households in different income groups along the regions' bus rapid transit and rail rapid transit corridors between 1996 and 2016. In our analysis, we mainly control for the factors that determine the availability of housing units and focus on the observed demand for housing, while hypothesizing the influence of rapid transit infrastructure on both constructs. This conceptual framework is presented in Figure 1, where blue color is used for the variables that we were able to obtain for the analysis, and gray represents the factors not available for this study. For example, in purely economic terms, the price can be considered as an explicit expression of the demand for housing, however access to this data is challenging in the Canadian context, so we use residential in-movement of households as the next-best proxy for that.

Naturally, the in-movement of new residents is affected by the availability of housing (Amborski, 2016) that we capture through the density, share of renters, and supply of new housing units. We hypothesize this relationship to be bi-directional, as a more conducive environment and higher supply should attract more residents, while higher demand should encourage developers to provide more housing options. Transit infrastructure is both the result of dense urbanized environments and also a factor that can transform the built environment (Cao et al., 2009). On the other hand, access to transit can be a desirable aspect of a household's residence, since it may provide more travel options and access to numerous opportunities (Mayer & Trevien, 2017). We also believe that transit infrastructure can mediate the effect of the built environment on the demand, either through dedicated policies that encourage the provision of certain types of housing next to transit infrastructure or by increasing the investment appeal for developers. At the same time, housing choices depend on the economic standing of a household (Baudry & Maslianskaia-Pautrel, 2016), so in this study, we also explore residential movement for various income groups, however, we do not have any information on their housing

location preferences, like the impact of the quality of schools, presence of parks, or neighborhood safety among the others (Walker & Li, 2007), though it is likely that they also play an important role. To investigate the influence of these factors on the in-movement of new residents, we employ a suite of statistical tests and corroborate the findings with the available relevant studies in the respective section. Nevertheless, the absence of information on how households relocated within the same study areas and how many left those altogether limited us to only conceptual consideration of the migration construct.
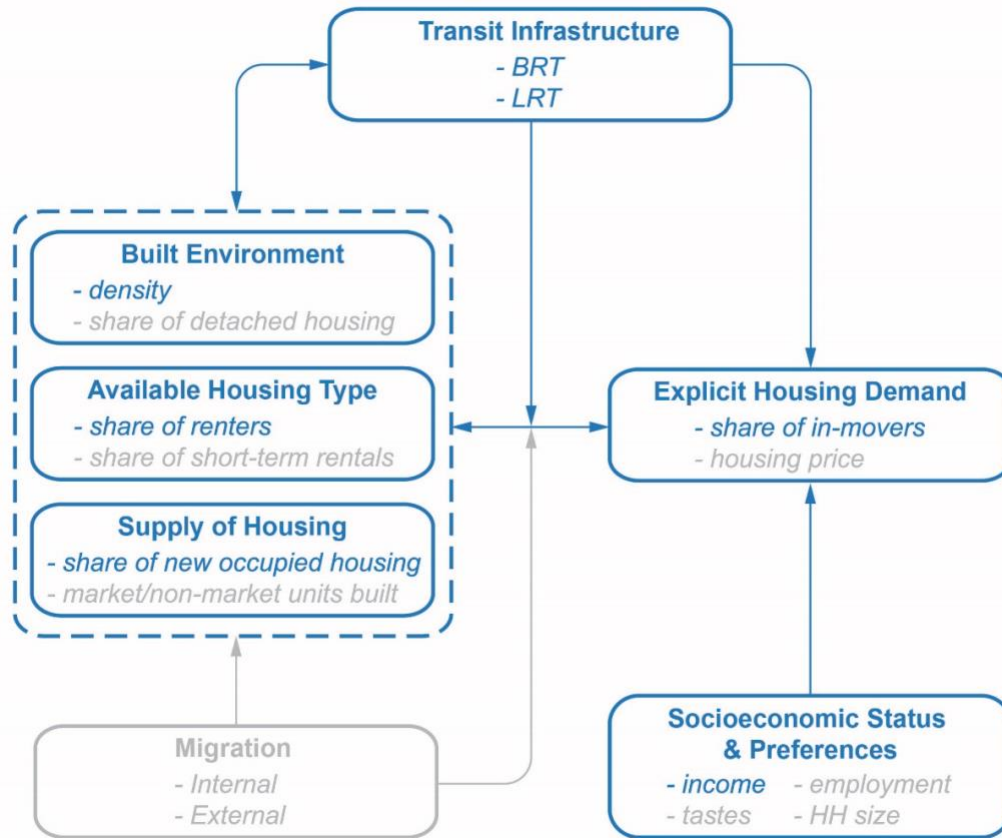

Figure 1. Conceptual framework of the study

We use this conceptual framework to investigate if the opening of a new rapid transit line affects the in-movement of households into adjacent areas and how this effect is distributed among different income and residential tenure groups. The results of this research aim to provide public transport agencies with a better understanding of the benefits and externalities of rapid transit technology (i.e., mode) in transit-adjacent neighborhoods.

Literature review

Existing research does not provide a uniform picture of the effects that transit investments have on the change in sociodemographic characteristics, valuation of real estate, and an inflow of higher-income households in adjacent neighborhoods. Our literature review suggests that outcomes vary between different communities and modes (i.e., light rail transit (LRT) or BRT) that are invested in. We have also found that local contexts, such as social factors (habits) and planning policy play an important role in the impact of new transit projects. It should also be noted, that although there is evidence of uniform impacts that rapid transit has on housing prices across the globe (Perk et al., 2017), for this review the authors intentionally focused on the US, Canada, and other countries with a comparable institutional and economic setting (i.e., democratic countries with a high level of economic development, where the planning and delivery of transit services follow a similar institutional framework), to understand where the study fits among research efforts with a similar context.

Baker and Lee (2017) looked at the impact of new LRT stations on neighborhood characteristics of 14 US urbanized areas, but their study did not reveal any universal reason for the change in the socioeconomic status of neighborhoods and is consistent with the findings of Nilsson and Delmelle (2018) along with Dong (2017). They concluded that the difference in local and regional planning efforts, like the existence or absence of dedicated transit-oriented development (TOD) and affordable housing strategies, led to different social and economic outcomes in transit-adjacent neighborhoods. Looking at Los Angeles, CA, Boarnet et al. (2018, 2019) found that neighborhoods around stations of LA Metro's two heavy rail and four light rail lines saw a significant decline in the share of lower-income households and an increase in the share of middle- to upper-middle income households from 1994 through 2012, indicating that opening of a new station was associated with a lower rate of in-movement of the poorest households, and the decline of move-out rates for households earning 30% to 50% of area median income. They speculated that the possible reason for the latter might be the higher value those low-income households place on improved transit access and their willingness to bear increased housing costs. Overall, that seems to be the trend for communities in California, as a similar rise of high-income households next to LRT lines was observed in San Jose and San Francisco (Chatman et al., 2019).

With a focus on the Canadian context, Grube-Cavers and Patterson (2014) found neighborhoods close to LRT stations show signs of gentrification in Toronto, ON, and Montreal, QC, but not in Vancouver, BC. At the same time, Jones and Ley (2016) found low-income housing in the suburbs along Vancouver's SkyTrain corridor to be endangered by gentrification, driven by upzoning and TOD initiatives that focus on the sustainability benefits of such approach but lack social objectives that can provide alternatives to lower density affordable housing stock that is being replaced. Finally, a longitudinal study by DeVries (2019) indicated that areas near new SkyTrain stations saw a larger relative share of lower-income households before the development of RRT, however, these neighborhoods shifted over time where relatively lower-income households were replaced by relatively higher-income households.

The relationship between BRT projects and changes in neighborhood characteristics has received considerably less attention from researchers than rail rapid transit. It should also be noted that many researchers use different interpretations of BRT systems. For example, Sidloski and Diab (2020) used the definition and data of the BRT+ Centre of Excellence that considers a corridor to be BRT if its vehicles have a distinct marketing brand and move along paved streets on wheels, they travel frequently at high speeds and have short headways (BRT + CoE, n.d.). Note, this definition does not include a

dedicated right-of-way, off-board fare collection, and other components required by the Institute for Transportation and Development Policy (ITDP) BRT Standard (ITDP, n.d.). In a comparison of BRT ridership in 16 small (under 500,000 residents) and medium (between 500,000 and 1.5 million people) North American cities, Sidloski and Diab (2020) found that station catchment areas in small cities tend to have a higher presence of seniors, renters, and households with lower median income when compared to medium-sized cities (Vancouver was not included in their analysis). This scarcity of knowledge is a result of the relatively recent introduction of BRT to many North American cities, which makes it challenging to examine how demographics have changed over time as the BRT operation may only span one or two census periods. Nevertheless, Brown's (2016) study of the areas adjacent to the Orange Line BRT in Los Angeles, CA provides some insights. The line was announced in 2001 and completed by 2005, so the author focused on the differences between 2000 and 2013 estimates and reported the rise of median home values, rents, and educational attainment of residents within a ½-mile radius of BRT stations when compared to those located 2 and 5 miles from stations, while neighborhood racial-ethnic compositions remained relatively static.

When examining the gentrification effects of new LRT and BRT stations that opened in US metropolitan areas between 2000 and 2009, Qi (2020) found that areas with a greater presence of households below the poverty line and without children had a higher propensity for gentrification. However, they also suggested no homogeneity between BRT and LRT impacts, with the former showing marginal change in the core set of indicators, namely median rent and median property value, the share of college-educated residents and those in professional trades, and median household income at the census block group level. Importantly, they also disaggregated data for the selected indicators by the type of BRT service provided, and changes that could be attributed to BRT stations were found for the high-quality service consistent with ITPD's definition (i.e., it operates on a dedicated right-of-way, receives priority traffic signals, uses off-board fare collection) and is referred to as "high-end BRT" by Qi (2020).

Finally, another body of research is specifically focused on the impact of BRT on real estate values. The introduction of BRT increased property values by 3.69% within 800 meters of the transit corridor in Auckland, New Zealand (Filippova & Sheng, 2020), and had a similar positive impact on housing prices in Pittsburgh, PA (Perk & Catalá, 2009) and Eugene, OR (Perk et al., 2017). On the other hand, Des Rosiers et al. (2005) looked at the changes in the value of single-family houses in Quebec City, QC, and found a mixed effect of proximity to the Métrobus corridors, a BRT-like high-frequency service (similar to B-Line service in Metro Vancouver) that operates predominantly on dedicated lanes. There, a combination of hedonic models showed that properties adjacent to the Métrobus service (within 50 meters) saw a 5.2% growth in value since its introduction in 1992. Conversely, the same study found that houses within 500 meters of the service in low-density outer neighborhoods, where it was introduced during subsequent expansions during 1992-1995, saw a 2.5% decline in their sale price. Des Rosiers et al. (2010) speculated that excessive presence of traffic, vehicle emissions, and noise associated with an increase in operations of local bus or the Métrobus services resulted in lower property values.

The present study aims to advance the scarce body of knowledge on the impacts BRT corridors have on the residential movement of different income groups in adjacent neighborhoods, as well as improve our understanding of whether there is a difference in sociodemographic outcomes that BRT and LRT projects bring. Existing literature on BRT effects is mainly focused on changes in ridership levels and housing costs, while the body of evidence on sociodemographic changes available for LRT projects can not be directly related to BRT due to the disparate outcomes that different rapid transit modes

bring to neighborhoods where they operate (Qi, 2020). By looking at the levels of household in-movement across the range of household income categories for BRT and RRT lines in Vancouver, BC, we examine the impacts of rapid transit investments on the sociodemographic composition of adjacent neighborhoods and build upon Qi's (2020) US findings for different rapid transit modes using a Canadian context.

Study context

Greater Vancouver is the third-largest metropolitan region in Canada and is comprised of 21 municipalities, one Electoral Area, and one Treaty First Nation. In 2016, the region was home to a population of 2,463,431 people living in 1,027,613 private households (Statistics Canada, 2017). TransLink is the public transport agency responsible for the planning, management, and operation of Metro Vancouver's regional transportation network. As of 2019, TransLink's service area covered more than 1,800 square kilometers with 245 bus routes and 79 kilometers of RRT serving 53 stations. Additionally, the agency is also responsible for a commuter rail line, a passenger-only ferry, and the region's major road network including several bridges (TransLink, n.d.-c). These factors, namely the mature dense urban environment served by both BRT and RRT lines that started operations at different times throughout the region make the context of Metro Vancouver a favorable pseudo-experimental setting for the exploration of the impacts of both types of rapid transit.

Based on the available data the scope of this study was set to all BRT and RRT lines that were in service for all or part of the 20-year period spanning 1996 through 2016. The spatial extent of the study lines is shown in Figure 2, while a summary of the service start and end dates is enclosed in Table 1.

Table 1. Summary of transit corridors service life

Transit Line	Technology	Service Start	Service End
97 B-Line	BRT	September 2002	December 2016[1]
98 B-Line	BRT	August 2001	September 2009[2]
99 B-Line	BRT	September 1996	In Service[3]
Expo Line	RRT	December 1985	In Service
Millennium Line	RRT	August 2002	In Service
Canada Line	RRT	August 2009	In Service

As previously discussed, researchers at times use different definitions of a BRT system. In the context of this study, we define BRT based on the characteristics of TransLink's B-Line routes.[4] Characteristics include a high service frequency with a distinct marketing, image, and fleet, as well as a dedicated busway in the middle of the road and curbside bus priority (i.e., queue jump lanes). It is noted that the latter features (namely dedicated busways and curbside bus priority) were characteristic of only the 98 B-Line (Transportation Research Board, n.d.), however, that has not impaired the overall success of the B-Line routes. For example, the 99 B-Line does not utilize a dedicated busway or curbside priority at all times of the day, yet was the busiest bus route in the

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[1] The 97 B-Line was discontinued and replaced by a Millennium Line (RRT) extension, the Evergreen Line.

[2] The 98 B-Line was discontinued and replaced by the Canada Line (RRT).

[3] A portion of the 99 B-Line is expected to be replaced by a Millennium Line extension, the Broadway Subway, expected to open in 2025.

[4] TransLink rebranded their B-Line service to RapidBus (for the exception of the 99 B-Line) in 2020.

TransLink network pre-COVID-19, with an average daily weekday boarding of 57,240 passengers in 2019 (TransLink, 2019). Similarly, we define RRT based on the characteristics of TransLink's SkyTrain routes. Some of these features include a fully automated, high-frequency, high-capacity service that operates completely separated from traffic, generally below ground or on an elevated structure above ground (TransLink et al., 2012). It should also be noted that generally, the RRT (or SkyTrain) mode referenced in this paper is comparable with respect to the characteristics and operations of many LRT systems referenced in the literature review. However, it is worth mentioning that TransLink documents have different definitions for LRT and RRT systems, largely based on passenger capacity: 6,000 to 10,000 people per hour for LRT versus 10,000 to 25,000 people per hour for RRT (TransLink et al., 2012). Currently, TransLink does not operate or is proposing to operate any LRT lines, and has RRT (SkyTrain) lines only.
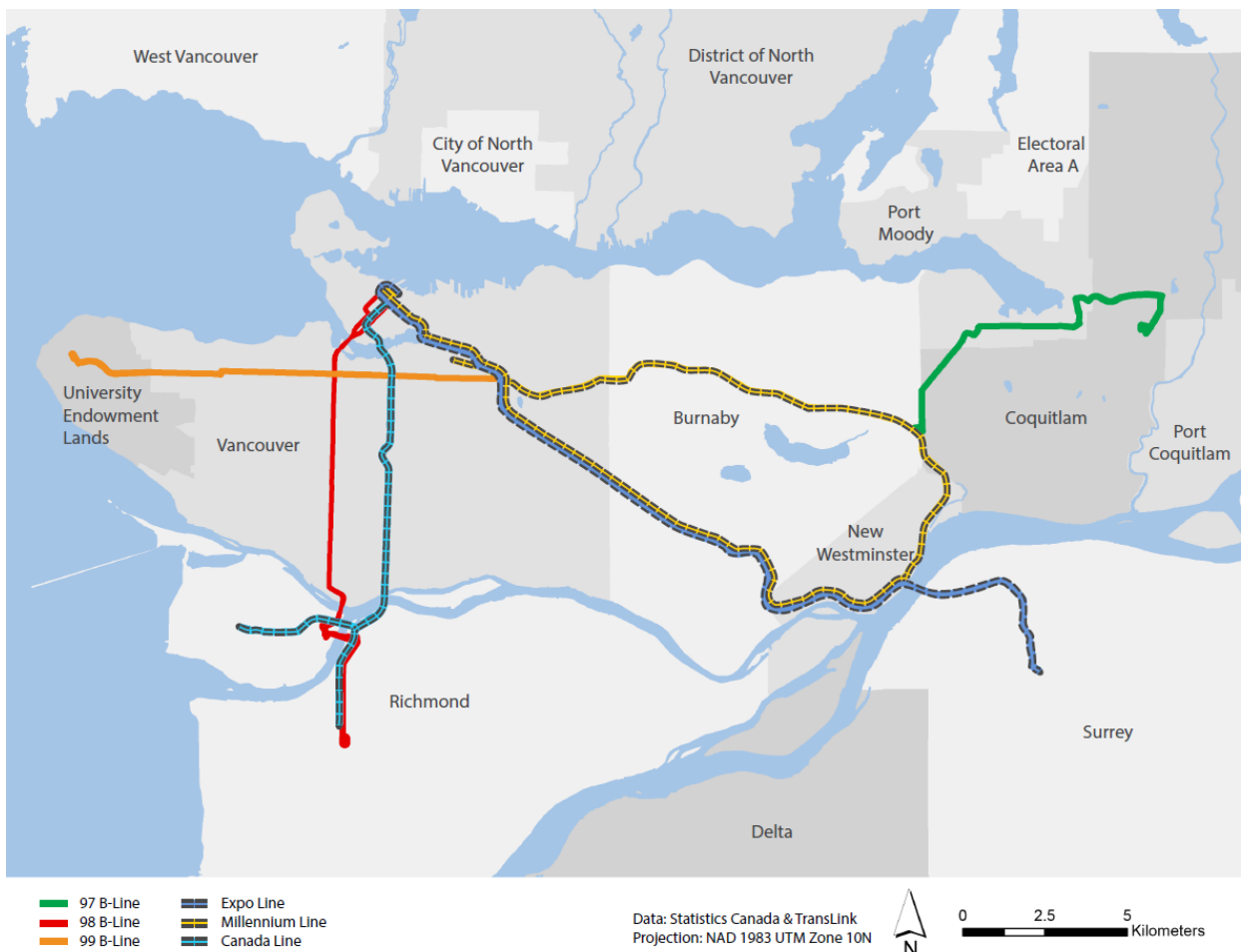

Figure 2. Study rapid transit lines

Service parameters of the study lines varied over the years, however, in broad terms both LRT and RRT lines offer comparable service. For example, all three RRT lines have a frequency of about 2-3 minutes at peak times during the weekdays, going up to 10 minutes for Expo and Millenium lines, and up to 20 minutes at some parts of the Canada Line late at night, operating from around 5 am until about 1 am (TransLink, n.d.-b). At

the same time, 99 B-Line, which is the last of the studied BRT lines still in operation, has a frequency similar to RRT throughout the day, though it provides service about one hour longer (TransLink, 2023). On the other hand, as of 2023, RRT fares vary by the time of day and the number of zones traveled ($3.15 for 1 zone full fare, and $6.20 for 3 zones), while BRT service has a single-zone fare as the other bus routes throughout the system (TransLink, n.d.-a).

It is further noted that the routing of some lines has varied over time. For example, the Expo Line only traveled as far as New Westminster before 1990; most 99 B-Line trips extended east of the current terminus until 2002; and two Millennium Line stations opened later than the rest of those along the corridor. Accordingly, the study corridors were defined to ensure the line geography was consistent for the entire study period. The Expo Line reached its current terminus prior to 1996 and therefore poses no issue; the segment east of the current terminus for most 99 B-Line trips was excluded to ensure all portions of the study geography were in service for the entire study period; and all Millennium Line stations had opened between the key 2001 and 2006 census years when data was collected, negating any consistency concerns.

Data and methods

The data used in this study were primarily obtained from Statistics Canada and collected during 2001, 2006, 2011,[5] and 2016 censuses. Custom table specifications were ordered for each census year containing mobility status—a place of residence five years ago and household income groups (generally by the $10,000 interval) for private households in occupied private dwellings by tenure type (owner or renter). To ensure that each income category across the census years represents the same purchasing power of the households that are in it, all income data was converted to 2015 dollars to account for inflation over the study period. The data were obtained at the Census Tract (CT) level, a Statistics Canada-defined unit of small, relatively stable geographies that usually have a population of fewer than 10,000 persons (Statistics Canada, 2017), for the Vancouver Census Metropolitan Area (CMA). All of the information obtained from Statistics Canada for CTs that split over the study period was weighted to match the 2016 Census CT boundaries using a mix of population and dasymetric areal weighting developed by Allen and Taylor (2018).

Households in each CT were then grouped into counts by standardized income groups, based on the average ($68,280) of the median Vancouver CMA household incomes in the 2001 through 2016 censuses. Standardized income groups were adapted from the Metro Vancouver Regional Affordable Housing Strategy (Metro Vancouver, 2016) and summarized in Table 2. It should be noted that Statistics Canada reports income in $10,000 increments, so the calculated income group ranges were rounded to the nearest lower bound of a given increment. For example, 50% of $68,280 translates into $34,140 which we rounded up to the lower bound of $30,000 for the Low Income group. After all the processing, this information was then transformed into the ratio of in-movers to the total CT population, the share of in-movers in a certain income bin to the total number of in-movers, and the share of renter in-movers for every income group.

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[5] The 2011 census was known as the National Household Survey (NHS). Although it contained all of the same questions a census would, most of the NHS was voluntary. Accordingly, concerns have been raised questioning the validity of data collected (Ontario Council of University Libraries, n.d.).

Table 2. Calculation of study income groups

Income Group	% of Median Vancouver CMA Households Income ($68,280)	Income Group Range	
Very Low Income	0% to 50%	$0 to	$29,999
Low Income	50% to 80%	$30,000 to	$49,999
Moderate Income	80% to 120%	$50,000 to	$79,999
Above Moderate Income	120% to 150%	$80,000 to	$99,999
High Income	150% to 200%	$100,000 to	$139,999
Very High Income	200% +	$140,000 +	

Other information that came from the census included the total population, total number of occupied units, total number of renter-occupied units, and the number of occupied units built in the 5 years before a respective census year. That data was weighted following the same approach used for mobility status variables and converted to population density, shares of renters, and shares of new housing in a census tract for normalization purposes. We also considered using the information on housing completions from Canada Mortgage and Housing Corporation (CMHC) to capture the impact of new housing supply, but at a CT level, it is publicly available only from 2012 and does not cover the full study period. Instead, we used the share of occupied units built in the 5 years before the census as a proxy. When we compared the 2016 Census values for newly household-occupied units and the 2012-2016 CMHC totals for housing completions, we found a high degree of similarity captured by a Pearson correlation coefficient of 0.96, suggesting the reliability of our selected proxy. We provide summary statistics for the values from the two sources in Table 3. On the other hand, when we considered another operational variable from the Census that is likely influential on the existing built environment—the share of detached housing, it appeared to be highly negatively correlated with the share of renters, suggesting that significant amount of renters in Vancouver Metro live in apartment buildings, resulting in the detached housing variable being disregarded from the analysis. Finally, transit line routing and stop/station data were obtained from TransLink's General Transit Feed Specification (GTFS) data and imported into ArcGIS software for analysis.

Table 3. Summary statistics for Statistics Canada newly household-occupied units and the CMHC totals for housing completions at the Census Tract level

	2016 Census newly household-occupied units	2012-2016 CMHC housing completions
Mean	180.6	193.7
Standard Deviation	280.6	345.9
Max	2580	3326
Min	0	0

Data preparation for this analysis also included the delineation of a set of affected CTs defined for each transit corridor as those having at least 50% of the boundary covered within 0 to 800 meters (½-mile) of a BRT stop or RRT station as measured by the ArcGIS Network Analyst tool. We selected an 800-meter network buffer, as it is a commonly cited walkshed for areas said to be affected by rapid transit service (Kuby et al., 2004; Weinstein Agrawal et al., 2008). These affected CTs were then coded as RRT and BRT dummy variables for the census years when those lines were in operation. At the stage of preliminary regression analysis, we tested the interaction between the two variables to investigate the potential effect of the presence of both rapid transit modes on

in-movement rates in a CT. This step did not produce statistically significant results, so we proceeded with the mode-specific dummy coding. Furthermore, because the Expo and Millennium lines share a significant portion of the same corridor, which can potentially make this area more attractive due to higher accessibility, we tested the observed difference in in-movement rates of 5.29 percentage points between this shared corridor and the other single line RRT corridors using a Mann–Whitney u-test and found it statistically significant (p = 0.0003). As a result, RRT CTs were further divided into the Expo-Millennium RRT Corridor CTs and single line RRT Corridor CTs, with only the former being statistically significant and retained for the final specification of the regression analysis.

Given the longitudinal nature of the data, analysis of the share of in-movers in the total population of CTs was performed using a multilevel regression framework that accounted for the variance of repeated observations for the same CT in a municipality across census years, and for the same municipality to account for the potential autocorrelation effects within the administrative boundaries. The final model can be expressed as follows:

$$Y_{ijk} = \beta_{ojk} + \beta_{1jk} * density_{ijk} + \beta_{2jk} * renters_{ijk} + \beta_{3jk} * new\ housing_{ijk} + \beta_{4jk} * BRT_{ijk} + \beta_{5jk} * RRT_{ijk} + \beta_{6jk} * BRT_{ijk} * new\ housing_{ijk} + \widetilde{u}_\iota + u_{ij} + \epsilon_{ijk}$$

where $\widetilde{u}_\iota$ is the error term across all CTs, municipalities, and time points, u_{ij} is the error term for CTs within municipalities, and ϵ_{ijk} captures the difference between the observed share of in-movers Y_{ijk} and mean share of in-movers for CT j from municipality i, with random intercepts for different municipalities and repeated observations of CTs. The summary statistics of the variables used for the regression analysis, as well as details about in-mover rates by income categories and transit-impacted CTs are available in Table 4.

Table 4. Summary statistics for the share of the in-movers model

Variable	Proportion	Mean	Std. dev
Share of in-movers (%)	-	44.15	12.09
Share of Very Low Income in-movers (%)	-	21.13	10.41
Share of Low Income in-movers (%)	-	16.20	5.73
Share of Moderate Income in-movers (%)	-	21.08	6.20
Share of Above Moderate Income in-movers (%)	-	10.76	4.21
Share of High Income in-movers (%)	-	13.83	6.28
Share of Very High Income in-movers (%)	-	14.82	10.76
Density (000s per sq. km)	-	4.30	4.40
Share of Renters (%)	-	32.43	19.31
Share of New Housing (%)	-	9.68	11.26
Expo-Millennium RRT Corridor Census Tracts	0.08	-	-
Share of in-movers in Expo-Millennium RRT Corridor Census Tracts (%)	-	51.69	12.57
BRT Census Tracts	0.12	-	-
Share of in-movers in BRT Census Tracts (%)	-	53.57	13.00

The other stages of analysis involved a comparison of in-movement rates of different income groups of all households, and specifically of renters. To parse those trends out, we only focused on the municipalities where BRT and RRT lines operated or remained in service, and compared the differences in respective rates between the CTs affected by rapid transit infrastructure, and a set of control CTs, unaffected by the presence of BRT or RRT lines. We limited the pool of control CTs to the municipalities where rapid transit

lines either operated or remained in service to maintain relative consistency in policy and regulatory environment, with the assumption being that municipalities without rapid transit lines might have different household movement dynamics and factors that influence them. We provide the list of those municipalities in Table 5 and the extent of the study area for that type of analysis with delineated affected and control CTs in Figure 3.

Table 5. Municipalities with census tracts affected by rapid transit infrastructure

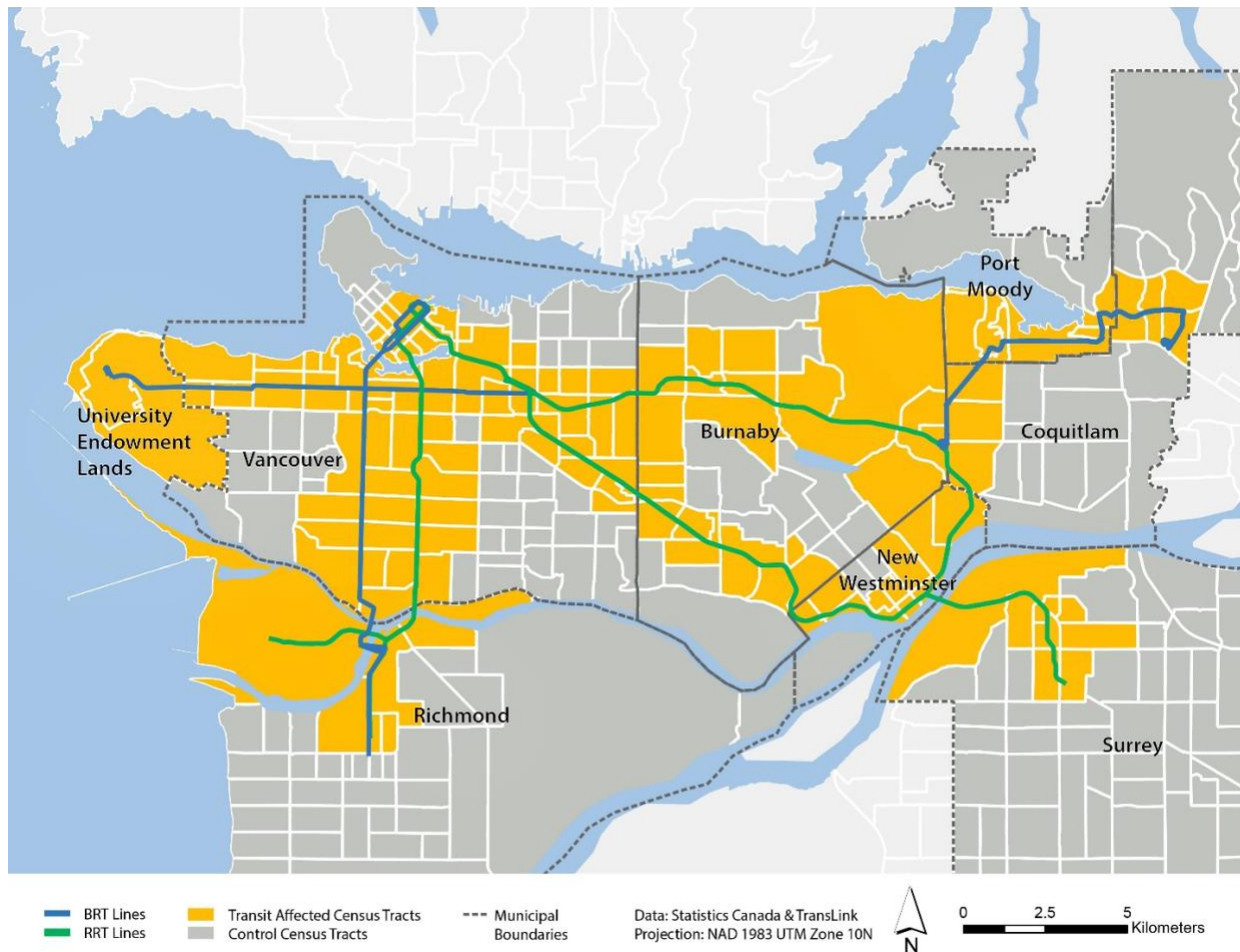| Type	Transit Line	Municipalities Served
BRT	97 B-Line	Burnaby, Coquitlam, Port Moody
	98 B-Line	Vancouver, Richmond
	99 B-Line	Vancouver
RRT	Expo Line	Vancouver, Burnaby, New Westminster, Surrey
	Millennium Line	Vancouver, Burnaby, New Westminster, Coquitlam
	Canada Line	Vancouver, Richmond

Figure 3. Affected and control census tract selection for the study area

In order to get additional insights into the region-wide trends, we investigate the residential in-movement at the level of every rapid transit line, and compare it to the CTs that are farther away from rapid transit lines. Since the Expo and Millennium RRT lines

share a significant portion of the same corridor, at this stage of the analysis the Millennium Line was only considered for the portion where the tracks are not shared with the Expo Line to avoid unnecessarily double-counting transit adjacent neighborhoods. Small sample sizes suggested the significance of the differences in the affected and control CTs to be evaluated using a Mann–Whitney u-test—essentially a t-test for nonparametric data—as our data could not be assumed to be normally distributed, and some samples contained less than 40 or 50 records required to ignore the non-normal distribution (Ewing & Park, 2020). These trends are visualized in Figure 4 and Figure 5 with the indication of the level of significance in the difference in a given year. We discuss the findings of the analysis in the respective section below.

Findings

The analysis in this paper is presented in three sections. We first discuss the results of the multilevel regression model where we analyze the impact of rapid transit infrastructure on the share of all households that recently relocated while controlling for the factors of the built environment, housing type, and supply of new units at a CT level. In the second stage of the analysis, we look at the household in-movement trends for every rapid transit line by different income groups. Lastly, we investigate the difference in in-movement for various income groups of renters.

1.1   The impact of rapid transit on the share of in-movers

At this stage of the analysis, we explored the influence of the proximity to either BRT lines or Expo-Millennium RRT Corridor on the total share of in-movers in a CT, while controlling for the local conditions, like the density of the built environment, the share of renters, and the percentage of recently built housing (our housing supply proxy). We employed the multilevel regression approach to account for the longitudinal nature of our data (records available for every CT from 2001, 2006, 2011, and 2016 Censuses), as well as to capture the autocorrelation effect for the CTs within the same municipality. The resulting model has a reasonably high marginal R^2 of 0.77, especially given that due to data availability, we were able to control for mainly the supply side of the housing. When looking at the model estimates provided in Table 6, it is easy to notice that the parameters we controlled for follow intuition. For example, the model suggests with 99% confidence that an increase in density by 1,000 residents per square kilometer will grow the share of in-movers by 0.46%, holding everything else constant at their mean. While it is fairly intuitive, as higher density means more units that people can occupy, higher density also means that local regulations allowed developers to supply more housing, which is often an objective for them (Margalit, 2012). Moreover, density may be an attractor for new residents on its own, as it correlates with the higher diversity and quality of private and public services (Kushner, 2002). It is also equally natural that on average a percent increase in the share of renters in a CT increases the share of in-movers by 0.37%, as it has been found in past studies that renters have higher mobility than homeowners (Baker et al., 2016). Lastly, the positive impact of increased housing supply on residential mobility is rather intuitive, as more housing units increase the potential for a larger number of households to move in. This trend has been also empirically confirmed by previous research (e.g., Mast, 2019).

Table 6. Share of in-mover model results

Variable	Parameter Estimate	99% CI	t-stat
Constant	24.85***	22.92; 26.89	34.78
Density (000s per sq. km)	0.46***	0.33; 0.59	9.10
Share of Renters	0.37***	0.34; 0.40	30.59
Share of New Housing	0.66***	0.63; 0.69	52.41
Expo-Millennium RRT Corridor	**-1.37***	**-2.64; -0.22**	**-2.37**
BRT	**4.17***	**2.59; 5.73**	**6.92**
Share of New Housing * BRT	**-0.01***	**-0.18; -0.01**	**-3.02**
N		1,847	
AIC/BIC/Log-likelihood		11,288.5/ 11,343.7 / -5,634.2	
Marginal R^2/Conditional R^2		0.77/0.87	
Random effects (City: CT): Constant		Variance: 10.2; SD: 3.2	
Random effects (City): Constant		Variance: 5.7; SD: 2.4	
Random effects: Residual		Variance: 19.3; SD 4.4	

Note: *p<0.1; **p<0.05; ***p<0.01

Shifting the focus to the variables of our primary interest (variables bolded in Table 6), we can see how the model suggests that on average census tracts impacted by BRT lines saw 4.17% more new in-movers, ceteris paribus. We hypothesize that this higher share is mainly driven by the oldest BRT line in operation in the region—99 B-Line that connects many students with the University of British Columbia. Students are a relatively mobile group, who likely relocate after they finish their studies, so, naturally, CTs adjacent to 99 B-Line see a higher rate of people moving in, especially when data is available quinquennially. On the other hand, we observe a decline of in-movers in the CTs adjacent to the Expo-Millenium SkyTrain Corridor as well as BRT lines where more new housing is being built. Given the variables we control for, we cannot assume that the observed trend is happening due to the existing density or limited supply of housing that precludes people from moving in. The effect of rental properties is also captured via a separate parameter in the model and should not affect the estimates for rapid transit infrastructure. A potential explanation is that the type of housing available or being built in those areas became less attainable to some income groups. This hypothesis goes in line with the previous findings that dense mixed-use housing (which is often found next to rapid transit lines in Vancouver) can be less affordable for both renters and owners (Moos et al., 2018). At the same time, it might be an indication of some of the properties being left unoccupied or even purchased only due to their investment potential (Lee, 2016), as well as their use as short-term rentals (e.g., Airbnb), which tend to dominate amenity-rich desirable neighborhoods (Wachsmuth & Weisler, 2018). We further investigate the impacts of rapid transit infrastructure on in-movement trends among different income groups and different income groups of renters in the following sections.

1.2   In-movement rates of all households by income

Here we look at the total in-mover rates for each transit corridor's affected and control CTs, along with an indicator of statistical significance (*p*-value) for the difference from the Mann–Whitney *u*-test. As previously mentioned, the control group is comprised of all CTs without adjacent rapid transit infrastructure located within the municipalities that have/had either BRT or RRT lines in a given census period - Burnaby, Coquitlam, New Westminster, Port Moody, Richmond, Surrey, and Vancouver. We present the findings in Figure 4. Although only 35 of the 216 pairs tested were determined to be statistically significant to some degree, they provide additional insights into the findings of the

regression model presented in Table 6. Observing corridor-level trends over the years, it is easy to note that for all studied corridors but the 97-B Line, the share of in-movers who made less than $30,000 is consistently above the levels of control CTs, with the difference ranging from 5% to 10% depending on the line. It is also important to note that along the 98 B-Line, Canada Line, and Expo Line, the share of low-income in-movers goes down, though it is still higher than for the control group. Zooming into the Expo Line (which is spatially equivalent to the Expo-Millenium RRT Corridor in the regression model), where the differences are consistently statistically significant from the control group, the in-movement rate of low-income households went down by a third between 2001 and 2016, while the rate of in-movers who make more than $140,000 doubled, though it has not reached the rate observed in the comparison group for that income bin. Overall, our findings suggest that there has been a decline in the share of low-income movers along the rapid transit corridors over the years and an increase in the share of high-income movers in some of the corridors, however, they remained either above or below the level of the control group in 2016, indicating that the trend might not be a result of the direct impact of rapid transit infrastructure, but redistribution of households from different income bins.
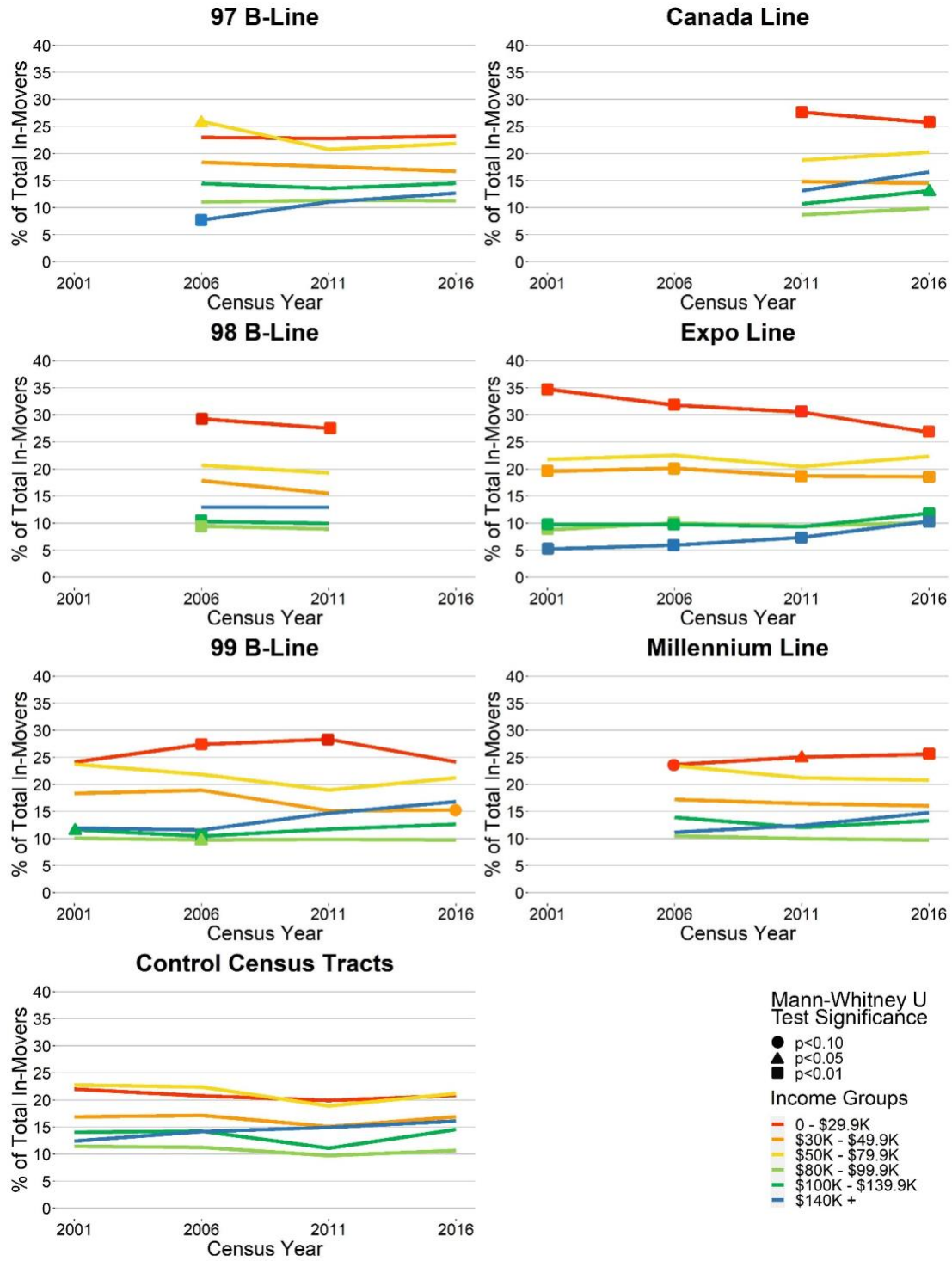
Figure 4. Household in-mover rates by income for transit-affected and control census tracts

1.3   The share of renters among in-movers by income

In this section, we further investigate the in-movement trends along the rapid transit corridors with a specific focus on the share of renters in each income group. As previously, we use the *u*-test to evaluate the statistical significance of the difference between the transit-affected and control CTs. The findings are presented in Figure 5. Before we go to the comparison, a few notable trends should be mentioned. First of all, consistent with the previous literature, we see that the share of renters in low-income groups is much higher across the board (Suttor, 2015). Secondly, a notable dip in the share of renters among in-movers can be observed throughout the study area in the 2011 Census, especially among the households making more than $100,000 annually, followed by an increase in the share of renters reported in the 2016 Census that was particularly steep for more affluent in-movers. Most likely, this was the result of the price decline that the Canadian housing market experienced in 2008 (MacGee, 2009; Wolf, 2010), potentially facilitating more households to opt for homeownership during those years. The Great Recession had a significant impact on the housing sector, and although Canada fared fairly well among the other prosperous countries, it still experienced a decline in economic activity (Boivin, 2011), potentially turning more households to renting in the latter years, the results of which we see in the numbers from 2016 Census. At the same time, we do not see this being the case for lower-income bins along the rapid transit lines, where the ratio of renters to owners remained relatively stable over the study period.

Focusing on the comparison of the transit-affected and control CTs, we see that areas adjacent to rapid transit lines generally saw more renters moving in, suggesting that it might be a reflection of the type of housing that is being offered there, and this difference is statistically significant across all income bins for all rapid transit lines but the 97 B-Line. This is of no surprise since even TransLink's transit-oriented development guidelines encourage developers to supply purpose-built rental housing next to transit infrastructure (TransLink, 2012). However, Figure 5 also suggests that rental housing the market provides is at a price attainable for more affluent households, as indicated by the increase in the share of renters among the high-income in-movers by 2016. This effect is especially pronounced for renters in the $100,000-$139,999 income bin, as their share increased from less than 50% to almost 60% along the Expo Line, from 30% to more than 40% in the CTs affected by Millennium Line, and from 45% to almost 60% if the trends for 98 B-Line and Canada Line are considered together (those lines served the same CTs at their respective times). At the same time, the rate of renters in the lowest income bin fluctuates at the same level along all rapid transit lines. We consider this observation to be substantiated by previous research which pointed to the complete decline in the development of new affordable housing in Canadian cities, developers' focus on the provision of market-rate units (Suttor, 2015), older and more affordable rental properties being replaced by denser developments (Metro Vancouver, 2016), as well as ongoing financialization (i.e., targeted procurement by financial trusts with the profit-maximizing objective) of rental housing in Canada (August, 2022).

Overall, the three layers of analysis performed in this paper suggest that areas adjacent to RRT lines in Metro Vancouver saw fewer in-movers between the 2001 Census and the 2016 Census, while the same was true for the CTs with a larger share of new housing affected by BRT lines. While we did not find evidence to state that the presence of rapid transit infrastructure disproportionately affected any one of the income groups, our analysis suggests that there were more affluent renters moving in along the RRT and BRT lines, while the share of low-income renters that relocated remained relatively stable.
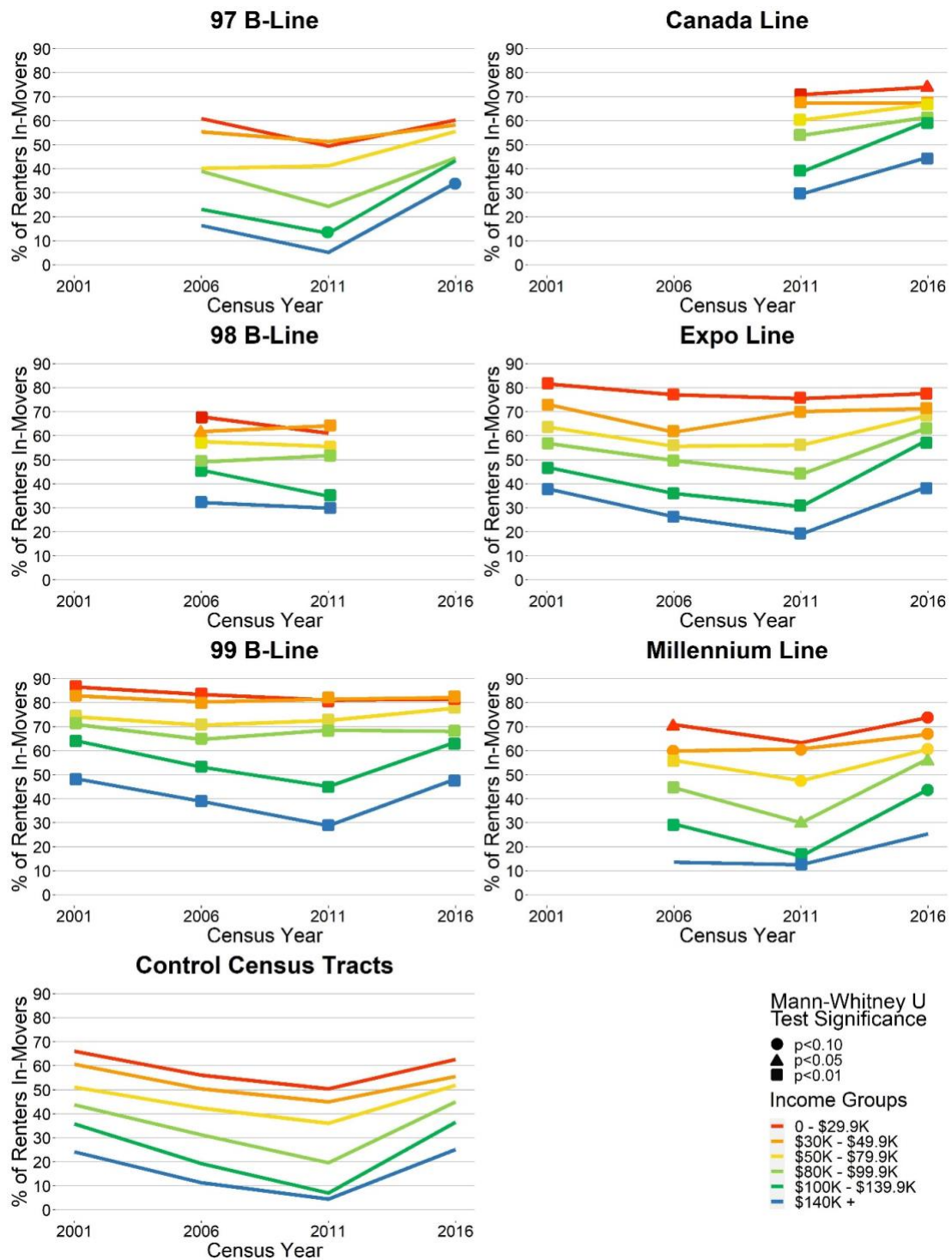
Figure 5. The share of renters among in-movers by income groups for transit-affected and control CTs

Discussion

This study investigated the impact of rapid transit lines on the in-movement of new households using multilevel regression and a comparison of in-movers rates between transit-affected and control CTs by income groups for all households and renters with a subsequent evaluation of the difference significance using Mann–Whitney *u*-test. We found that on average fewer households move into CTs adjacent to Expo-Millenium SkyTrain Corridor, and CTs with BRT lines that saw a larger than average increase in new housing—potentially due to some of that housing being used as an investment, but not as a primary residence. At the same time, we identified that the share of renters among the high-income households that moved close to rapid transit lines increased, which might indicate the lack of provision of new rental affordable housing in those areas. In principle, our findings point to the similar conclusion that Chernoff and Craig (2022) made in a recent study—households in higher-income bins likely benefit from the rapid transit infrastructure in Metro Vancouver more than lower-income ones. The Expo Line provides the most clarity on these trends given it has been in service the longest, dating back to 1985. Furthermore, these findings are consistent with Jones and Ley (2016) as well as DeVries (2019).

The implications of these findings are twofold. We identified that some neighborhoods adjacent to transit had a higher presence of low-income residents in the past, and the in-movement of affluent families might have made those areas more balanced, increased the tax base, and as a result the quality of services for all residents. On the other hand, given the overheated real estate market of Metro Vancouver (Rherrad et al., 2019), it is valid to assume that there are also parts of the region where more affordable rental housing might be replaced with rental units geared towards higher incomes. As our study found, proximity to rapid transit infrastructure increases the attractiveness of nearby areas and results in a larger share of higher-income renters who can potentially price out lower-income households if the supply of affordable housing remains the same. Some municipalities are more successful in addressing these issues than others and provide valuable lessons to other communities that face similar challenges. Since 2018, Sound Transit, a public transit agency in the metropolitan region of Seattle, WA, has been providing up to 80% of surplus land left after the construction of its LRT stations for the development of affordable housing units as a legacy of its equitable TOD policy (Sound Transit, 2018). Similarly, Baker and Lee (2017) reported on the progress of Metro's TOD Strategic plan in facilitating the development of below-market price units next to rapid transit in the Portland region, OR. There, the plan receives support in funding from the Metropolitan Regional Council and in 10-year property tax abatements from the State of Oregon. On the other hand, they suggest that the absence of such TOD planning focused on density increase before the development of rapid transit infrastructure might be the reason for the low ridership and swaths of undeveloped areas around LRT stations in St. Louis, MO (Baker & Lee, 2017). Lastly, it is important to mention that the authors arrived at a sobering conclusion that even the presence of a dedicated transit-oriented affordable housing fund might not be a sufficient intervention for such an overheated market as in San Francisco, CA, as it will not be able to provide a meaningful amount of affordable units due to exorbitant housing costs.

Policy considerations with respect to TOD-induced neighborhood change are more relevant than ever in Vancouver today. Our analyses provide clear evidence that both SkyTrain and B-Line corridors can affect the sociodemographic makeup of adjacent areas. Given the forthcoming expansion of both SkyTrain (Millennium Line Broadway Extension, Expo Line Langley Extension) and B-Line (12 new routes planned to be established between 2018 and 2027) in Metro Vancouver, careful policy intervention

should be considered to limit any negative externalities while providing high-quality transit to the region.

Conclusions

This paper has filled an important gap in understanding the effects of transit investments in general, and the socioeconomic impact of transport technology choice. Using Metro Vancouver as a case study, we found patterns indicating less residential movement into CTs adjacent to Expo-Millennium RRT Corridor, and areas with more new development around BRT lines. We also identified the trend of more affluent renters moving into those areas, while the share of low-income renters to homeowners remained relatively the same. Overall, this research adds more evidence to the notion that the provision of any type of rapid transit infrastructure can not be executed in a vacuum, without consideration and careful planning for the surrounding land use, housing, and social fabric. We bring light to BRT having unintended social consequences that were, perhaps, not considered previously. The findings of this study are very timely given the broader adoption of BRT in North America.

Several limitations of the analysis data should be acknowledged. Given that information came from census rather than administrative records, it was not possible to track specific households across time like Boarnet et al. (2018, 2019), rather only the cumulative totals in each CT. Accordingly, it is possible that some households moved along the income group spectrum over time without moving dwellings. On the other hand, the census tract itself may not be the perfect geographic unit to define affected and comparison areas. Some CTs included in the affected group may be fully within the 800-meter network radius of the BRT stop or RRT station while others may be partially contained within the network buffer. This means that while some households in CT can access the B-Line or SkyTrain station within a 10-minute walk, other households cannot. Administrative data of individual households would allow for a better understanding of a household's proximity to a rapid transit station. However, the CT is the finest possible geography in which data can be reliably obtained given that any smaller geographies would be subject to increased suppression by Statistics Canada in order to protect the identity of residents.

While our research brings in new evidence on the effects of rapid transit infrastructure, it also highlights the need for continued exploration of the relationship between rapid transit access and the change in neighborhood sociodemographic canvas. Our study exposes differences in transit-affected areas relative to comparison groups, however, future research is necessary to account for various factors that appeal to people's preferences, such as the presence of amenities (e.g., shopping, schools, parks, employment, hospitals, and recreation sites) or the age, quality, and type of housing available near transit corridors to measure how much influence the transit mode has relative to other important variables.

Author acknowledgment

Funding acknowledgment

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