The Journal of Transport and Land Use http://jtlu.org
Vol. 15 No. 1 [2022] pp. 375–398

The role of transit accessibility in influencing the activity space and non-work activity participation of different income groups

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Abstract: Improved accessibility by transit service constitutes a critical component in removing spatial barriers in daily mobility for disadvantaged groups. However, the effects of transit accessibility on the daily mobility and activity participation of different social strata remain inconclusive. This study investigates the role of transit accessibility on the activity space of three income groups in Hong Kong. The results show that the availability of transit stations and network accessibility by mass transit rail (MTR) are significantly linked to the spatial extensiveness of activity space of the higher- and medium-income commuters, while bus plays a more important role for the daily mobility of the low-income group. Concerning non-work activity participation, the low-income non-commuters appear less affected by the availability of MTR stations than the other two groups, suggesting a potentially lower ability of using MTR to carry out different daily activities. Our findings offer some in-depth insights into the possible social inequality of using transit service, thereby contributing to a more nuanced understanding of the relationship between transit accessibility and mobility in relation to economic status. Policy recommendations to alleviate transport disadvantage and improve social equity are proposed.

Keywords: Transit accessibility, activity space, activity participation, social equity, income

Article history:
Received: August 28, 2021
Received in revised form: December 24, 2021
Accepted: May 8, 2022
Available online: July 8, 2022

1 Introduction

Uneven mobility across social groups has long been of concern among urban scholars (Hernandez, 2018; Morency et al., 2011; Urry, 2006). The urban poor have often been deficient in economic and transport resources needed for daily mobility and activities (Kenyon et al., 2003; Lucas et al., 2016).

http://dx.doi.org/10.5198/jtlu.2022.2075
ISSN: 1938-7849

The *Journal of Transport and Land Use* is the official journal of the World Society for Transport and Land Use (WSTLUR) and is published and sponsored by the University of Minnesota Center for Transportation Studies.

As a result, compared to the general public, they tend to be more constrained in daily mobility, and less active in participating in the various social and economic activities in the society (Adeel et al., 2016; Giuliano, 2005; Huang et al., 2018; Tao et al., 2020). The lack of mobility and relatedly, the ability to access activity opportunities, in turn, can result in social exclusion and degrading well-being of the low-income populations (Currie & Delbosc, 2010; Lucas, 2012; Ma et al., 2018).

Transit systems serves as a major role in ensuring spatial connection of different parts and population groups across a city (Huang et al., 2021; Wu et al., 2019). And provision of accessible and well-connected public transit service has been deemed as a critical component for improving the mobility conditions of the urban poor who cannot afford to own private cars (Giuliano, 2005; Pathak et al., 2017; Welch, 2013). Through improved transit accessibility (i.e., the easiness of accessing different activity opportunities over space by public transit), it is expected that the urban poor will have better access to different activity opportunities scattered across urban space that are essential for an improved livelihood (e.g., employment, education) (Moreno-Monroy et al., 2018).

However, public transit in certain cases has been found to fail to adequately meet the mobility needs of the urban poor, due to issues such as imbalanced distribution of transit service relative to demand (Dong, 2017; Guzman & Oviedo, 2018; Zhao & Zhang, 2019), which to some extent is at contradiction with social equity and justice (Hernandez, 2018; Preston, 2009). Within different city contexts, it has been found that transit service mainly serves to connect locations with high concentration of economic activities (e.g., central business districts, job centers), while being largely under-provided in urban fringes and other isolated areas wherein certain under-privileged households reside (Delbosc & Currie, 2011; Delmelle & Casas, 2012; Grengs, 2010; Martínez et al., 2018). Moreover, as more cities are now pursuing transit-oriented development (TOD), the capitalization of mass transit service into the land and housing market may markedly increase the living cost in certain transit-adjacent neighborhoods (Dong, 2017; Duncan, 2011; He, 2020), in effect making mass transit a less affordable transport options for the low-income.

Although the issue of transit service inequality (e.g., disparity in access to public transit) has been well-recognized, how it may have differentiated effects on different social groups is not fully understood. Existing research has largely focused on assessing the extent of under-provision of transit service and uneven transit accessibility especially for the low-income population (Delbosc & Currie, 2011; Martínez et al., 2018). However, the impacts of transit service on the different dimensions of daily mobility (e.g., spatial extensiveness, activity participation) of the disadvantaged groups remains relatively under-studied. Furthermore, few studies have investigated the disparity across different transit modes in affecting mobility conditions. Different transit modes usually have distinctive service attributes and have been linked to urban development and land value to varying degrees (Cao & Porter-Nelson, 2016; Efthymiou & Antoniou, 2013). Hence, their roles in daily mobility and activities may also vary across different social groups. Acquiring such knowledge, we consider, will contribute to an enhanced evidence base to inform more equitable transit planning.

This study seeks to address the above knowledge gaps by investigating the relationship between transit accessibility and the activity space of the low and higher income groups in Hong Kong. Drawing on the 2011 travel characteristics survey (TCS) and transport network data, we first measured accessibility by different transit modes (Mass Transit Railway, or MTR, and bus) across the study context. Next, we investigated the effects of transit accessibility on activity space of the low-income and other groups via a suite of statistical analyses. The modeling results offered a relatively mixed picture: that transit accessibility exerted stronger effects on the activity space of the higher-income (and to a lesser extent, the medium-income) groups than the low-income, whilst its influence on the non-work activity participation was somewhat stronger among the low-income non-commuters.

The rest of the study is structured as follows. Section 2 provides a brief review of the relevant literature and identifies the research gaps. Section 3 describes the methodology, data source and study context. Section 4 presents the results of analysis. Finally, Section 5 summarizes and discusses the main findings, before some policy recommendations are drawn.

2 Literature review

2.1 Daily mobility, activity space of the urban poor and their social outcomes

Substantial research has unveiled to what extent the urban poor are less mobile compared to the other groups, and what social outcomes and implications of low mobility can be expected (Currie & Delbosc, 2010; Henriksson, et al., 2021; Hine & Mitchell, 2017; Preston & Raje, 2007). Research works in this area have been largely driven by transport-related social exclusion (Hine & Mitchell, 2017; Mackett & Thoreau, 2015; Preston & Raje, 2007). According to the well-known report published by the Social Exclusion Unit (SEU) (2003), transport and mobility possess a critical bearing on social exclusion (i.e., being deprived of the ability to participate in society such as working and shopping). For the more disadvantaged groups such as the low-income, the deficiency of economic and transport resources can limit one's ability to traverse space and access various activity opportunities, which, in turn, may lead to social exclusion and deteriorating well-being (Currie & Delbosc, 2010; Kenyon et al., 2003; Lucas, 2012; Motte-Baumovl & Nassi, 2012).

The concept of activity space has been widely applied to capture the overall mobility and the ability to engage in various activities over space (Kwan, 1998; Li & Tong, 2016; Scott & He, 2012). Originated from time geography by Hägerstrand (1970), activity space has been defined as the geographic area within which one is able to carry out daily travel and activities (Silm & Ahas, 2014). Recent research has also extended the concept of activity space to include behavioral dimensions related to activity participation such as the frequency or participation time in certain activities (e.g., Silm & Ahas, 2014; Wang & Li, 2016). With everything else being equal, a relatively higher level of mobility (e.g., larger activity space) coupled with encounters with more various activity opportunities are considered beneficial for mitigating social exclusion (Preston & Raje, 2007; Tao et al., 2020).

Drawing on the concept of activity space, research in the developed context (e.g., North America, Europe) indicated that carless households and those in the urban fringe are more likely to experience limited mobility, and as such, higher risk of social exclusion in daily life. For example, focusing on three Canadian cities, Morency et al. (2011) found that three disadvantaged groups (the elderly, low-income and single-mother households) in suburban areas traveled an overall shorter distance compared to other groups. In a Germany based study, Schönfelder and Axhausen (2003) did not find significant difference in daily mobility between the low-income and other groups, potentially due to the small income disparity of the study context. In the greater Melbourne area, Delbosc and Currie (2011) found that some 20-24% of the residents in the urban fringe areas reported that they could not participate in certain social and leisure activities as they intended. In rural Ireland, Kamruzzaman and Hine (2012) revealed that the activity space of the low-income group tended to be aligned more with public transit routes than the higher-income groups, suggesting their limited ability of exploring activity opportunities at more distant areas due to the lack of private cars.

Beyond the North-American and European contexts, the mobility of the urban poor and the implications for social exclusion have also received increasing interest. Focusing on Hong Kong, Wang and Li (2016) found that the activity space (captured by the spatial extensiveness and activity-participation indices) was largely comparable between public and private housing residents. Yet, the two groups also showed distinct spatial segregation in terms of the activity locations. Also in Hong Kong, Tao et al. (2020) found that between 2002 and 2011, the activity space of the low-income commuters did not improve significantly, despite the marked expansion of the rail transit system. In Nanjing, China, Wang et al. (2020) found that accessibility to transit service and other facilities (e.g., commercial) was markedly lower for the low-income than for the others, which significantly restrained the former's activity space.

Overall, the aforementioned research largely confirmed the importance of transport resources in influencing the activity space and social participation of low-income groups. However, limited research has investigated whether accessibility by public transit service (or transit accessibility) may exhibit differentiated effects on the activity space across different social strata, which might be more prevalent within a highly transit-oriented context. A few studies have tapped on this dimension (e.g., Tao et al., 2020; Wang et al., 2020), however, a more comprehensive examination is still lacking. We further elaborate on this issue and its significance in the following section.

2.2 Transit service, transit accessibility, and socio-spatial inequality

Considerable research has examined the potential link between transit service and socio-spatial inequality. The research in this area can be divided into two groups: the first focuses on the spatial distribution of and uneven access to transit service; while the second group pays attention to the affordability issues associated with transit service. Concerning the former, Delbosc and Currie (2011) constructed a composite index of transit supply based on a suite of service indicators (e.g., service catchment, frequency) in Melbourne. They found that nearly 70% of the population had walkable access to around 20% of transit service, suggesting a highly imbalanced distribution of transit demand and supply. Similar analytical works have been carried out in other similar cities (e.g., Ricciardi et al., 2015) as well as other parts of the world, including South America (e.g., Jaramillo et al., 2012) and Europe (e.g., Fransen et al., 2015). In these works, refined measures of transit demand and supply have been developed to better quantify the gaps of transit provision.

Apart from the above research, another strand of works has drawn on accessibility measures to quantify how well transit service may connect different activity opportunities for the disadvantage groups, which also pertains to the issue of transit inequality (e.g., Delmelle & Casas, 2012; Ermagun & Tilahun, 2020; Guzman & Oviedo, 2018; Martínez et al., 2018). In addition to the spatial layout of transit service, these studies have shown that policy factors including location choice of public facilities (e.g., schools), transit-fare subsidy and social housing policy can all profoundly shape accessibility by transit service especially for the vulnerable groups. Hence, it has been contended that in improving transit accessibility, both transit system improvement and broader social policy schemes should be taken into consideration (Martínez et al., 2018; Welch, 2013).

Regarding the affordability issue associated with transit service, whether cost of using transit service (in particular, fares) creates excessive financial burdens to the urban poor has been a major concern (Serebrisky et al., 2009). Compared to other income groups, the low-income earners have been found to generally spend a disproportionately larger part of their income in daily transport, which can restrict their use of transit service and therefore, overall mobility (Falavigna & Hernandez, 2016; Guzman & Oviedo, 2018). Furthermore, scholars have also employed transit affordability measures to assess the potential impact of adjustment of transit fare price on the low-income households (Zhao & Zhang, 2019).

Another issue related to affordability raises from the impact of transit service on the housing market. In particular, public transit has often considered as a valued urban amenity (Kahn, 2007; Yang et al., 2020). When coupled with other features such as pedestrian friendly design, lands in the precincts of a transit service are often of a higher market value than the lands farther away, which in turn can result in higher housing price and rent of the nearby areas (Dong, 2017; Duncan, 2011). Despite certain mixed results (e.g., Cao & Porter-Nelson, 2016), empirical research suggests that the possibility of mass transit service being capitalized into land and housing market cannot be precluded, especially in dense, transit-oriented cities such as Hong Kong (Cervero & Murakami, 2009; He et al., 2020) and Beijing (Dai et al., 2016; Huang et al., 2019). In such cases, higher living cost in the transit-oriented neighborhoods may make transit service less affordable for the low-income residents (Dong, 2017; Grube-Cavers & Patterson, 2015).

While there has been a growing interest, the current understanding of the link between transit service and socio-spatial inequality is still incomplete. In the literature, the inequality of transit service has been largely assessed on the potential demand for transit. However, it remains unclear how existing transit service may exhibit varying effects on the overall daily mobility of different income groups. Further, affordability may vary across transit modes due to both differentiated fare schemes and the stimulating effect on housing market. Given the spatial unevenness in transit system and the associated affordability issue, it is also worth comparing the effects of different transit modes on the mobility of different social groups.

3 Methodology

3.1 Hypotheses

As noted above, transit accessibility has been mainly captured from two dimensions, i.e., availability of transit stations within a reachable distance and network accessibility by transit service (Xu et al., 2015). In the current study, we also focused on these two dimensions. A distinction from previous research is that we focused on both commuters and non-commuters who are not in the labor market. Concerning social strata, we distinguished between three income groups, namely the low-income (below half of the median income level), the medium-income (between half of the median level and the median income level), and the higher-income (above the median income level. This categorization, we expect, will help provide more nuanced insights than the previous research as well (for more details about the categorization, readers are referred to see Tao et al., 2020).

Previous research found that the availability of transit stations was linked to larger activity space due to increase in non-work trips (e.g., Hong et al., 2014; Tana et al., 2016). However, the link between network accessibility by transit and the overall activity space has been limitedly examined. Given that higher job accessibility tends to shorten commuting trips (Kawabata & Shen, 2007; He et al., 2020), we expect that higher network accessibility by transit will also increase travel for non-work purposes, and therefore, enlarge activity space. As such, the first two hypotheses tested are:

H1: The availability of transit stations and higher network accessibility by transit increases activity space for both commuters (after controlling for commuting distance) and non-commuters.

H2: The availability of transit stations and higher network accessibility by transit increases non-work participation for commuters after controlling for commuting distance.

As discussed above, in a transit-oriented context, using transit service (especially rail-based transit) might be less affordable for the low-income than the others. Given this, we expect that the availability of transit stations and higher network accessibility by transit will exert a stronger effect on the activity space of higher-income individuals, followed by the medium-income and low-income groups. Hence, the third hypothesis:

H3: For both commuters and non-commuters, the availability of transit stations and network accessibility by transit will exert stronger effects on the activity space (both size of activity space and non-work activity participation) for the higher-income, followed by the medium-income, and the weakest effect among the low-income.

We also expect that the relevance of transit accessibility to different types of non-work activities will also vary. Due to the more dynamic and random nature of non-work activities, such variability remains to be revealed in the empirical analysis.

3.2 Measurement of availability of transit stations and network accessibility by transit

For availability of transit stations in a given area i (TS_i), we estimated the number of MTR station entrances or bus stops within a 500-meter distance (operationalized by network distance) from the centroid of a given area (in this case, Street Block or SB—the smallest geographic unit of census). 500-meter was used given that it was considered as the main catchment area of transit service (particularly MTR in Hong Kong) (Tang et al., 2004). To be consistent, we also used this distance for measuring accessibility for both MTR and bus.

There are numerous ways of measuring network accessibility, ranging from simple travel time to more complicated models such as doubly constrained models (Páez et al., 2012; Merlin & Hu, 2017). Compared to the access to a particular type of activities (e.g., jobs), we are more interested in network transit accessibility (NA_i) defined as the easiness of reaching other places by public transit modes. Following previous research that drew on a similar perspective (e.g., Giuliano et al., 2012; Krizek, 2003), the expression for estimating this network accessibility is written as:

$$NA_i = \sum_j e^{-\beta d_{ij}} \quad (1)$$

Where: β is the corresponding impedance parameter; d_{ij} represents the travel cost between locations i and j. In line with some previous research (e.g., He et al., 2018; Tao & He, 2021), travel cost is operationalized as travel time, which includes access, egress and transfer time when taking a transit mode (i.e., MTR, bus) between locations i and j. Travel time is estimated as the shortest network distance (time) using the network analysis module in ArcGIS.

Considering that locales will differ in terms of the number of non-work facilities, the attractiveness may also vary across places. As such, it makes more sense to weight the network accessibility in Equation (1) by the amount of non-work facilities. However, such information was not available at the time of this research. As a proxy, we weighted the network accessibility by population in a given place (P_j)[1], hence the expression:

$$NA_i = \sum_j e^{-\beta d_{ij} P_j} \quad (2)$$

Given that we aim to distinguish network accessibility between transit modes (in particular, MTR and bus), mode-specific impedance parameters (β) were estimated. Following previous research (e.g., Chaloux et al., 2019), we derived trips by bus and MTR, and fitted the cumulative proportions associated with different trip durations by the two modes to exponential decay curves. The decay factors derived were then used as impedance parameters for bus (β=-0.024) and MTR (β=-0.026).[2]

[1] We also experimented with weighting by number of jobs, which resulted in quite similar outcomes. Hence we stick to using population as the weight.

[2] We have also estimated the network accessibility with the inverse of the average travel time by MTR and bus. The results were largely the same as using the mode-specific decay factors.

3.3 Measurement of activity space

In line with previous research (Li & Tong, 2016; Wang & Li, 2016) the current study measures activity space mainly on two dimensions, the spatial or geographic extensiveness of mobility and activity participation.

Several indicators have been developed to capture the spatial extensiveness of activity space, including standard deviational ellipse, minimum convex polygon and distance traveled. Following previous research (Tao et al., 2020), we adopted standard distance circle (SDC) to represent the spatial extensiveness of all mechanized trips, as such capturing all activity locations accessed by mechanized modes (e.g., MTR, bus, cars). This approach was selected due to: 1) many individuals in the sample only had two unique trip locations; and 2) SDC has been found to be highly correlated (e.g., Pearson correlation>0.7) with other geographical measurements of activity space such as distance traveled and standard deviational ellipse (Kamruzzaman & Hine, 2012). The estimation of SDC follows the expression:

$$\mathrm{SD} = \sqrt{\frac{\sum_{i=0}^{n}(x_i - \bar{X})^2}{n} + \frac{\sum_{i=0}^{n}(y_i - \bar{Y})^2}{n}} \tag{3}$$

Where: x_i and y_i are the projected coordinates of a trip destination i; X and Y are the coordinates of the mean center of all locations; and n is the total number of locations. The SDC is the circular area (in km^2) estimated using SD as the radius (i.e., $SDC=\pi SD^2$).

3.4 Measurement of non-work activity participation

Given that most individuals in the TCS data visited only a limited number of activity places apart from home, resulted in very small range and variation. As such, we focused on whether an individual had engaged in non-work activities on the survey day to approximate the activity participation dimension of activity space. Following previous research (e.g., Tao & He, 2021), we distinguished two main types of non-work activities: maintenance (e.g., visiting a hospital, going to a bank) and discretionary (e.g., going to a restaurant, visiting a friend, going to parks/playgrounds). Two binary variables were generated to represent whether one has participated in discretionary or maintenance activities (yes=1, no=0).

3.5 Modeling analysis

Regression modeling analysis was employed to investigate the relationship between the availability of transit stations (TS_i) and network transit accessibility (NA_i) for commuters and non-commuters respectively. Other related variables were also controlled for, including a series of personal characteristics (e.g., age, gender, employment status, income level) and attributes related to household composition (e.g., household size, whether having dependent children and retired elders, and residential location). These variables were extracted from the 2011 TCS data. Home-workplace distance (HWD, captured by Euclidean distance) was included to control for the effect of commuting distance on activity space especially for commuters.

Neighborhood characteristics, particularly population density, employment density, median household income (monthly) at the neighborhood level and residential region (e.g., Kowloon, Hong Kong Island), were also included in the modeling analysis to control for neighborhood-level built environment and socio-economic composition. Multiple linear regression was employed. And binary logistic regression was employed to the model the relationship between transit accessibility and non-work activity participation.

For multiple regression analysis, estimator with robust standard errors was employed, which relaxes the assumption that residuals are independent and identically distributed, hence being able to produce more reliable estimation of the significance level of the coefficients (Hoechle, 2007). Given that the non-work participation can be considered a rare event among the commuters, for this group, the penalized estimator proposed by Firth (1993) was employed for the logistic regression analysis. Among non-commuters, non-work activity participation was more common. As such, standard logistic regression with robust standard errors was adopted. The modeling analysis was first carried out for commuters and non-commuters separately, and next, for different incomes groups of the two categories (as described below). For non-commuters, the variable of *HWD* was excluded. The modeling analysis was conducted with STATA 14.

3.6 Data source

The current study mainly drew on two sources of data. The first one is the 2011 Travel Characteristics Survey (TCS) of Hong Kong. The TCS data store detailed individual trip-making information on a weekday, including trip time, trip origins and destinations at the Street Block level (SB, the smallest geographic unit of census), trip purposes and transport modes. It should be noted that mainly mechanized trips were provided in this data set, while walking trips were not provided. Individual and household characteristics were also recorded in the TCS data. Second, transport network data that include the spatial layout of MTR stations were obtained mainly from the Transport Department of Hong Kong, while information about bus routes and stops was extracted from Hong Kong's Public Transport Atlas (Public Transport Atlas, 2010). For the current study, we focused on individuals who were 18 years or older. Certain cases with missing information (e.g., unreported income) and traveled outside Hong Kong on the survey day were removed.[3] The final sample size is 40,492 (32,625 commuters and 7,867 non-commuters). Apart from the two data sources, census data in 2011 was also employed to derive neighborhood characteristics.

3.7 Study context

Hong Kong is the study context (Figure 1), which is an Asian world city and adjoins the Southern border of Shenzhen. It consists of three main areas, Hong Kong Island (HK Island), Kowloon and New Territories (NT). HKI and Kowloon constitute the city's urban areas where the city's pillar industries (e.g., financial business, retailing) concentrate. NT is the suburban region where new towns serve as the main habitations. As of 2016, the population of Hong Kong is around 7.35 million. About 3.5 million residents live in the new towns, while majority of the rest lives in the urban areas (Civil Engineering and Development Department, 2016).

[3] Tertiary students were also excluded, given that they represent a relatively special group of people.

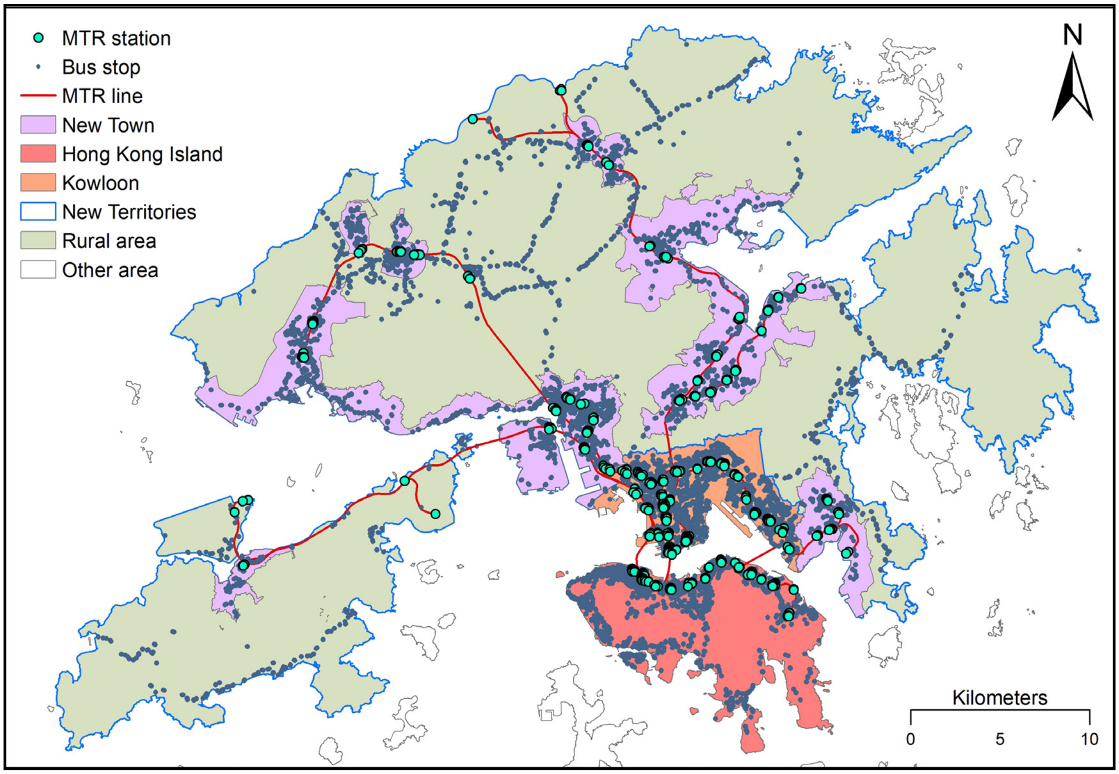


Figure 1. Study context
Note: Other area includes mainly isolated islands.

Hong Kong is well known for its highly developed transit system that mainly consists of Mass Transit Rail (MTR) and bus (franchised bus and mini-bus). These two modes account for over 70% of all daily mechanized trips, while the rest are taken by private cars and other minor modes such as ferry, LRT, tram and taxi. Hong Kong is also known for transit-oriented development, which has been operationalized through a "rail-plus-property" model (or "R + P" model). The "R + P" model has ensured highly synchronized development of rail transit and the adjacent land, but also lead to capitalization of the rail transit into the land market, as such increasing housing price especially nearby MTR stations (Cervero & Murakami, 2009; He et al., 2018).

Poverty in Hong Kong has been a pronounced issue. Low education attainment and joblessness are among the main causing factors of poverty in Hong Kong. The poverty rate in 2011 was 19.6% (or 1.3 million) (Census and Statistics Department, 2013). In the current study, low-income individuals were identified based on monthly household income and household size, which means that the poverty lines vary for households of different sizes.

4 Results

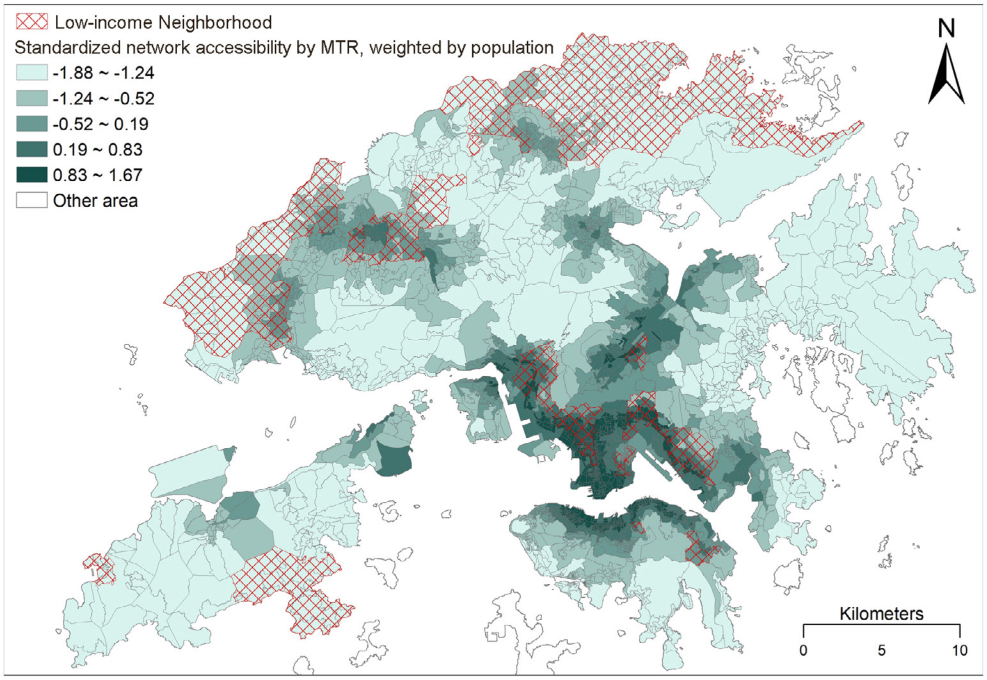
4.1 Descriptive statistics

The socio-demographic characteristics of the sample are displayed in Appendix A. Compared to commuters, non-commuters consist of more female, elders and married individuals. The household size of the latter group also tended to be smaller than the former. There also existed a higher proportion of retired elders but a lower proportion of dependent children at home for non-commuters than commuters. These suggest that non-commuters consisted of more retired individuals.

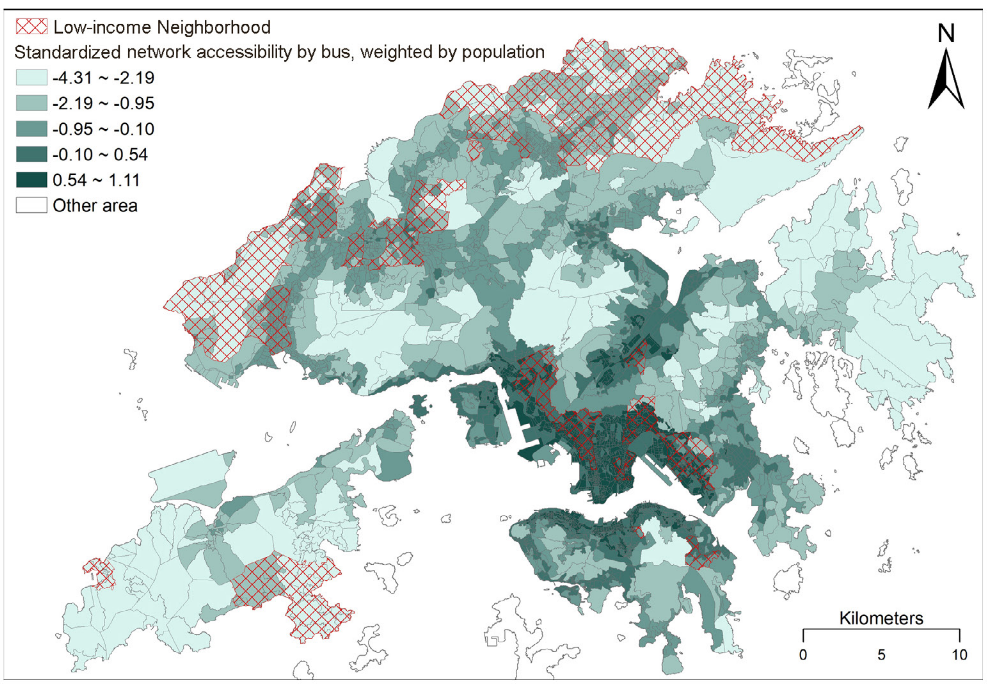
Certain consistent distinctions can be observed across the three income groups for both commuters and non-commuters. Specifically, a slightly higher proportion of the low-income individuals were female, while reverse was the case for the medium-income and higher income groups. Considerably higher proportions of the low-income and medium-income individuals resided in public housing estates than the higher-income. The higher-income group was also associated with higher proportions of multi-earner households, availability of private vehicle, but lower proportion of dependent children and retired elders at home than the other two groups. Moreover, somewhat higher proportions of the low-income and medium-income individuals resided in Kowloon than the higher income, which might be attributed to the concentration of low-income households in certain old urban areas (e.g., Kowloon City and Wong Tai Sin). It also appeared that on average, the higher-income individuals tended to reside in neighborhoods with lower population density but higher employment density than the other two groups, suggesting their ability to afford better living environment and more convenient locations.

4.2 Transit accessibility and activity space

Figure 2 illustrates the network accessibility by MTR and bus overlaid with the low-income neighborhoods. Similar to some previous research (e.g., Foster, 1994; Gravelle & Sutton, 2009), neighborhoods with the median household income in the bottom quartile across Hong Kong were identified as the low-income based on the 2011 Census. The revealed patterns indicate that network accessibility is discernibly higher in the urban areas than in the suburban areas. Clusters of areas with higher accessibility can also be found in certain new towns. An examination of local accessibility (the availability of MTR station entrances and bus stops) indicated a basically similar spatial pattern. Some low-income neighborhoods can be spotted in northern and western parts of NT where transit accessibility is lower, and in certain parts of Kowloon and small areas in HK Island where transit accessibility is higher.



(a)



(b)

Figure 2. Network accessibility by MTR and bus overlaid with the low-income neighborhoods in 2011

Table 1 compares the availability of transit (MTR and bus) stations and network transit accessibility across income groups. Through conducting chi-square test and ANOVA, for both commuters and non-commuters, it was found that the higher-income individuals enjoyed better access to MTR stations than the two other groups, but not for bus. Significantly higher network accessibility by MTR and bus was found for the low-income commuters than the other two groups, while reverse appeared to the case among non-commuters. This suggests that certain low-income commuters managed to reside in some more convenient locations to be closer to their workplace (e.g., Kowloon).

For commuters, significantly larger SDC was detected for the higher- and medium-income groups than the low-income, which is basically in line with previous research (e.g., Morency et al., 2011). For non-commuters, such difference was not detected. Concerning non-work participation, conducting chi-square tests showed that a higher proportion of higher-income commuters engaged in maintenance and discretionary activities than the other two groups. For non-commuters, the medium-income group appeared to engage in slightly more maintenance activities and less discretionary activities than the other two groups.

Table 1. Comparison of local and network transit accessibility and activity space across income groups

	Commuters			**Non-commuters**		
	Higher-income (N=23,022)	Medium-income (N=8,240)	Low- income (N=1,363)	Higher- income (N=3,626)	Medium- income (N=2,429)	Low- income (N=1,812)
Availability of transit stations						
Average number of MTR station entrances within 500 meters	1.76	1.52	1.50	1.77	1.57	1.48
Average number of bus stops within 500 meters	22.939	24.437	24.709	21.74	22.87	23.63
Network accessibility						
Average accessibility by MTR	0.149	0.152	0.227	0.138	0.123	0.082
Average accessibility by bus	0.250	0.240	0.313	0.263	0.236	0.239
Activity space						
Average SDC (km^2)	95.97	91.82	74.82	46.44	42.98	41.38
Participating in maintenance activities (%)	3.57	1.72	1.91	64.12	65.09	61.64
Participating in discretionary activities (%)	5.10	2.79	1.91	45.04	39.65	44.32

4.3 Modeling results for activity space

Prior to formal modeling analysis, we examined the pairwise correlations among the independent variables, which were mostly below 0.7. For the full sample analysis, an ordinal variable was created to capture the level of income. In the regression analysis, the variance inflation factor (VIF) of the other independent variables were mostly lower than 4, indicating the absence of severe multi-collinearity issue.

Table 2 presents the modeling results for activity space in terms of SDC. Significant model fit was achieved for all models. For commuters, the derived coefficients explained over 88 percent of the variance in SDC, which, as indicated below, can be largely attributed to the inclusion of home-work distance. For non-commuters, around 8 to 12 percent of SDC's variance was explained, indicating a more heterogeneous pattern of activity space compared to the commuters. Overall the model fit appeared to be acceptable.

Concerning the key variables of interest, the availability of MTR stations was found to be negatively linked to SDC (representing the geographical size of activity space), while a positive effect was found for network accessibility by MTR. The former finding appeared to disagree with our first hypotheses, suggesting that with everything else being equal (particularly in terms of home-work distance), better access to MTR stations reduced the size of activity space. There are two plausible explanations for this observation: 1) better access to MTR stations might reduce possibly longer, detouring trips when traveling between MTR stations and home; and 2) certain facilities such as retails and other services tended to concentrate around MTR stations which might reduce the need for mechanized travel of some commuters on weekdays. On the other hand, the availability of bus stops was found to exert a positive effect on SDC, whilst a negative effect was found for network accessibility by bus. Although the former finding aligns with our expectations, the latter may in part reflect the higher density and relatively broader coverage of the bus network, which, we expect, reduced the need of long-distance travel as well.

Regarding group difference, conforming our hypothesis, accessibility by MTR (both availability of stations and network accessibility) and the availability of bus stops appeared to exert marked effects on SDC among the higher-income, but less so for the medium- and low-income. Such distinction was less ostensible concerning the effect of network accessibility by bus. These suggest that MTR might play a more important role in daily mobility for the higher income than those of lower socio-economic status, implying possible inequality of experience with using MTR.

Among non-commuters, the availability of MTR stations and bus stops was found to exhibit a positive effect on SDC (Table 2), which is in line with our hypothesis. This suggests that in the absence of commuting trips (and working responsibilities), better access to transit stations encouraged trip-making. Network accessibility by MTR was largely insignificant, while a negative effect was found for network accessibility by bus. Across different income groups, it appears that again, the effects of the availability of MTR stations was stronger among the higher-income than for the other two groups. The availability of bus stops was significant mainly among the medium-income group. The effects of network accessibility by bus also appeared to be significant across all groups without marked distinction.

Regarding the controlled variables, at the overall level, household income was negatively linked to SDC. This may partially be related to controlling for the home-workplace distance in the model. After removing this variable, the effect of household income became positive, which is in line with previous research (e.g., Tao et al., 2020). Group-specific effects were detected for public housing and household size. Female and higher age of the medium-income group were also positively related to SDC, which might partially reflect the household responsibilities associated with these groups. Neighborhood characteristics including population and employment were also significantly linked to SDC, reflecting the effects of different built-up areas (e.g., residential versus working places) on activity space. Compared to the HK Island, living in Kowloon was associated with significantly larger SDC, while living in the new towns and rural areas was linked to markedly smaller SDC especially for the higher- and medium-income commuters. This might be attributed to the higher concentration of retailing and other services in the urban areas.

For non-commuters, income was positively linked to SDC, suggesting that without commuting trips, the higher-income non-commuters might travel further and more than the low-income peers. At the group level, female and age was found to be linked to smaller SDCs of the medium- and low-income groups respectively. And living in public housing and larger household size were also associated with smaller SDC for the higher-income group, whilst having dependent children was negatively related to

SDC except for the low-income. As for different regions, living in Kowloon and new towns was associated with larger SDC compared to living in the HK Island, while reverse was the case for living in the rural areas.

Table 2. Modeling results for SDC (natural log transformed) of the full sample and income groups

	Commuters				Non-commuters			
	All (N=32,625)	Higher-income (N=23,022)	Medium-income (N=8,240)	Low-income (N=1,363)	All (N=7,867)	Higher-income (N=3,626)	Medium-income (N=2,429)	Low-income (N=1,812)
Personal characteristics								
Female	0.020	-0.002	0.014***	0.007	-0.042***	-0.029*	-0.065***	-0.031
Age	0.006**	0.004*	0.010***	0.011	-0.046***	-0.032	-0.037	-0.081***
Household characteristics								
Income level[4]	-0.006**	-	-	-	0.044***	-		
Public housing	-0.010***	-0.008***	-0.021***	-0.009	-0.017	-0.044**	0.036	-0.025
Household size	0.005**	0.004	0.010**	0.007	-0.043***	-0.042**	-0.039*	-0.035
Having dependent children	-0.003	-0.003	-0.004	-0.008	-0.051***	-0.051***	-0.062***	-0.040
Having a retired elder	-0.003	-0.001	-0.006*	-0.004	-0.017	-0.025	-0.012	-0.011
Having a domestic helper	-0.001	-0.002	0.003	-0.007	-0.011	-0.014	-0.007	-0.008
Having a private vehicle	0.005**	0.004	0.012**	-0.010	0.018	0.013	0.012	0.020
Home-work distance	0.929***	0.931***	0.928***	0.913***	-	-	-	-
Location and neighborhood characteristics								
Kowloon	0.008***	0.006**	0.013**	0.029*	0.119***	0.137***	0.095***	0.088***
New Towns (New Territories)	-0.039***	-0.045***	-0.025***	-0.015	0.170***	0.200***	0.132***	0.121***
Rural areas (New Territories)	-0.026***	-0.024***	-0.035***	-0.035**	-0.061***	-0.059**	-0.067**	-0.058*
Population density (natural log transformed)	-0.011***	-0.007**	-0.017***	-0.046**	-0.031	-0.036	-0.025	-0.046
Employment density (natural log transformed)	0.033***	0.033***	0.025***	0.047***	0.071***	0.070**	0.016	0.166***
Median household income at the neighborhood level (natural log transformed)	-0.016***	-0.012***	-0.028***	-0.028**	-0.007	-0.011	0.035	-0.029
Transit accessibility								
Availability of MTR stations	-0.016***	-0.020***	-0.004	0.006	0.037**	0.065**	0.028	-0.022
Network accessibility by MTR	0.031***	0.039***	0.012*	0.004	0.0003	-0.031	0.058*	0.007
Availability of bus stops	0.025***	0.028***	0.014***	0.020	0.040***	0.036*	0.077***	0.030
Network accessibility by bus	-0.104***	-0.108***	-0.089***	-0.119***	-0.334***	-0.306***	-0.421***	-0.316***
Constant	-13.492	-36.473***	73.198***	95.368	61.628*	83.040*	-23.083	132.546
Model fit								
F	4314.00***	3312.75***	1158.59***	150.12***	26.68***	15.30***	11.12***	6.15***
Adjusted R^2	0.8863	0.8836	0.8949	0.8865	0.1044	0.1110	0.1240	0.0879

Note: the coefficients are standardized

***p<0.01, **p<0.05, *p<0.1

[4] An ordinal variable was created to capture the level of income in the full-sample analysis, with 1=low income, 2=medium income, and 3=higher income.

4.4 Modeling results for non-work activity participation

Table 3 presents the modeling results for non-work activity participation of commuters. Based on the Wald χ^2, significant models were achieved for higher- and medium-income groups, but not for the low-income. Yet, some interesting results were obtained for the accessibility variables. In the full sample, the availability of MTR stations exhibited insignificant effects on both maintenance and discretionary activity participation, which is also the largely case for network accessibility by MTR, except for a negative effect of this variable on discretionary activity participation. A positive effect was found for the network accessibility by bus on the participation of discretionary activities, while a negative effect was found for the availability of bus stops, suggesting better connection by bus, instead of access to bus stops, increased the likelihood of this type of activities. Across different groups, it appears that the role of transit accessibility in non-work activity participation was relatively small. Significant effects were mainly found among the higher-income than the medium- and low-income cohorts. This is partially in line with our hypothesis.

Regarding the models for the non-commuters (Table 4), the pseudo R2 ranged from over 0.03 to above 0.05. It has been pointed out that the pseudo R2 for logistic models tends to be considerably lower than that of the linear regression models. In addition, the Wald χ^2 was all significant. Hence, we consider model fit was acceptable.

Turning to the variables of interest, it was found the availability of MTR stations reduced the likelihood of participating in maintenance activities. This, again, is indicative of the possibility that enhanced link to MTR stations and more walking-accessible facilities around MTR stations might reduce the need for mechanized trips, including those of maintenance purposes, while possibly encouraging more walking trips. Network accessibility by MTR was found to be insignificantly associated with the likelihood of conducting maintenance trips for different income groups. The availability of bus stops and network accessibility by bus were largely insignificant or marginally significant, except for a positive effect of network accessibility on the maintenance activity participation of the higher-income group. An interesting observation, however, is that the effects of the availability of MTR stations were weaker for the low-income than for the other two groups (significant at the $p<0.1$ level than $p<0.01$ level), partially confirming our hypothesis.

Concerning discretionary trips (see also Table 4), significant positive effects were found for the availability of MTR stations across all groups except for the low-income. This suggests that better access to MTR stations to some extent better facilitated discretionary activities for the higher- and medium-income groups. A negative effect of network accessibility by MTR was also found among the higher-income group. While this finding contradicts with our hypothesis, a possible explanation is that for certain members of this group, the lower MTR accessibility was compensated by car ownership, which also facilitated discretionary trip and activities. Other accessibility indicators were largely insignificant or exhibited a marginal effect, except for a positive effect of availability of bus on the discretionary activity participation of the low-income. Yet, again, the effect of the availability of MTR stations appeared to be weaker for the low-income than for the other two groups.

Certain discernible patterns for activity patterns vis-à-vis socio-demographic characteristics can be identified for the full sample and the different income groups (except for the low-income). For both maintenance and discretionary activities, higher likelihood of activity participation was linked to higher income, living in private housing and smaller household size (except for maintenance activities of non-commuters). Female was associated with more likelihood of participation in maintenance activities, but lower likelihood of participation in discretionary activities especially among non-commuters. Group-specific effects were found for having dependent children, having a domestic helper and private-vehicle ownership particularly for the higher-income in terms of their participation in maintenance activities.

Table 3. Modeling results of non-work activity participation of commuters [5]

	Maintenance activities				Discretionary activities			
	Full sample (N=32,625)	Higher-income (N=23,022)	Medium-income (N=8,240)	Low-income (N=1,363)	Full sample (N=32,625)	Higher-income (N=23,022)	Medium-income (N=8,240)	Low-income (N=1,363)
Personal characteristics								
Female	0.298***	0.262***	0.365**	0.574	0.074	0.109*	-0.092	0.154
Age	0.004	0.004	0.0001	0.004	-0.004	-0.005	-0.003	0.027
Household characteristics								
Income level	0.328***	-	-	-	0.341***	-	-	-
Public housing	-0.530***	-0.574***	-0.591***	-0.040	-0.314***	-0.319***	-0.280	-1.029*
Household size	-0.117***	-0.126***	-0.047	0.004	-0.295***	-0.319***	-0.197*	0.115
Having dependent children	0.632***	0.719***	0.419**	-0.562	0.051	0.122	-0.257	0.159
Having a retired elder	0.104	0.093	0.193	-0.165	0.197**	0.165	0.361**	-0.204
Having a domestic helper	0.254***	0.223**	0.084	1.955**	-0.034	-0.056	0.145	0.210
Having a private vehicle	0.397***	0.377***	0.559*	1.021	0.432***	0.447***	0.395	0.105
Home-work distance	-0.009	0.003	-0.068***	-0.026	0.002	0.001	0.012	-0.086*
Location and neighborhood characteristics								
Kowloon	0.064	-0.085	0.732**	2.607*	0.129	0.097	0.240	0.947
New towns (New Territories)	-0.029	-0.135	0.578*	1.844	-0.083	-0.137	0.036	1.415
Rural areas (New Territories)	-0.169	-0.106	-0.875	-0.377	-0.581***	-0.568***	-1.182	2.275
Population density (natural log transformed)	0.013	-0.026	0.315**	-0.384	-0.034	-0.061	0.058	0.572
Employment density (natural log transformed)	-0.097***	-0.058	-0.367***	-0.266	0.034	0.049	-0.049	-0.131
Median household income at the neighborhood level (natural log transformed)	-0.160	-0.202*	0.070	-0.509	-0.155*	-0.198**	0.038	-0.265
Transit accessibility								
Availability of MTR stations	-0.015	-0.012	-0.002	-0.118	0.006	0.004	0.018	0.065
Network accessibility by MTR	0.046	0.063	-0.029	-0.272	-0.121*	-0.125*	-0.079	-0.222
Availability of bus stops	-0.004	-0.004	-0.002	0.014	-0.015***	-0.016***	-0.009	-0.053**
Network accessibility by bus	0.028	0.104	-0.363	-0.185	0.342***	0.399***	0.022	0.901
Constant	-1.932	-0.480	-4.590	5.356	-1.063	0.657	-3.064	-6.594
Model fit								
Wald χ^2	352.20***	254.64***	65.03***	22.36	351.03***	240.64***	30.73**	15.95
AIC	8447.309	6743.833	1355.718	221.428	11262.77	8921.731	2012.596	226.464
BIC	8623.559	6904.717	1496.053	325.776	11439.02	9082.615	2152.931	330.813

***p<0.01, **p<0.05, *p<0.1

[5] For the logistic models with a Firth estimator, pseudo R^2 was not provided in STATA, hence not reported here.

Table 4. Modeling results of non-work activity participation of non-commuters

	Maintenance activities				Discretionary activities			
	Full sample (N=7,867)	Higher-income (N=3,626)	Medium-income (N=2,429)	Low-income (N=1,812)	Full sample (N=7,867)	Higher-income (N=3,626)	Medium-income (N=2,429)	Low-income (N=1,812)
Personal characteristics								
Female	0.270***	0.172**	0.413***	0.253**	-0.237***	-0.176**	-0.331***	-0.225**
Age	-0.014***	-0.020***	-0.009**	-0.008	0.014***	0.021***	0.010**	0.006
Household characteristics								
Income level	-0.052	-	-	-	0.114***	-	-	-
Public housing	0.076	0.081	0.128	-0.152	-0.178***	-0.173*	-0.129	-0.064
Household size	0.057**	0.068**	0.005	0.163***	-0.103***	-0.115***	-0.052	-0.195***
Having dependent children	0.512***	0.445***	0.660***	0.295	-0.346***	-0.181*	-0.502***	-0.310*
Having a retired elder	-0.039	0.081	-0.165	-0.056	0.079	-0.117	0.212*	0.192
Having a domestic helper	-0.120	-0.144	-0.033	-0.098	0.153*	0.187*	0.014	0.133
Having a private vehicle	0.052	0.035	0.137	-0.028	-0.024	-0.055	0.019	0.270
Location and neighborhood characteristics								
Kowloon	-0.199**	-0.318***	-0.150	0.070	0.175**	0.294***	0.186	-0.132
New Towns (New Territories)	-0.024	-0.177	0.096	0.251	0.081	0.203*	0.005	-0.198
Rural areas (New Territories)	0.448***	0.337	1.059***	-0.005	-0.187	-0.006	-0.692**	-0.147
Population density (natural log transformed)	-0.055	-0.118**	0.006	0.019	0.078**	0.135***	0.045	-0.009
Employment density (natural log transformed)	0.017	0.0009	0.058	-0.035	-0.045*	-0.016	-0.072	-0.051
Median household income at the neighborhood level (natural log transformed)	0.095	0.125	-0.060	-0.053	-0.039	-0.123	0.197	0.182
Transit accessibility								
Availability of MTR stations	-0.042***	-0.033**	-0.052***	-0.042*	0.043***	0.042***	0.044**	0.033
Network accessibility by MTR	0.054	0.075	-0.018	0.055	-0.071	-0.161**	0.088	-0.019
Availability of bus stops	-0.004*	-0.002	-0.005	-0.009*	0.002	-0.002	0.002	0.108**
Network accessibility by bus	0.100	0.228**	0.203	-0.155	-0.030	-0.036	-0.199	0.059
Constant	-0.052	1.323	0.885	1.327	-0.964	-0.954	-2.448	-1.460
Model fit								
Wald χ^2	376.37***	172.44***	145.06***	105.21***	351.62***	147.87***	138.36***	106.89***
Pseudo R^2	0.0390	0.0383	0.0509	0.0465	0.0344	0.0317	0.0448	0.0448
AIC	9933.157	4590.095	3020.687	2338.633	10430.12	4870.466	3154.263	2415.086
BIC	10072.57	4707.817	3130.796	2443.175	10569.53	4988.188	3264.372	2519.627

***p<0.01, **p<0.05, *p<0.1

Regional differences in activity participation were found mainly between Kowloon, rural areas and HKI, but less so for new towns. Moreover, employment density and neighborhood-level median household income were found to be more relevant for the non-work activities of commuters, whilst population density played a more significant role for non-commuters.

5 Discussion and conclusions

This study has presented a detailed investigation of the role of transit accessibility in shaping the activity space of different income groups. While an accumulating body of research has highlighted the inequality in transit accessibility experienced by the disadvantaged groups (Guzman & Oviedo, 2018), few have shed light on the behavioral impacts of transit accessibility for different income groups. The current study seeks to address this deficit through empirically testing a series of hypotheses concerning the relationship between transit accessibility and activity space across income groups. The results confirmed disparity existed between income groups in the effects of transit accessibility on activity space. The key findings are summarized and key implications discussed below.

Our descriptive results indicated that the higher-income group enjoyed significantly better access to transit service. However, the low-income commuters emerged as more advantageous in terms of their neighborhoods' network accessibility by MTR and bus. These findings suggest that proximity to MTR indeed served as valued amenity among the higher-income commuters, whilst the low-income commuters still managed to live in locations with better network connection of transit service. Regarding activity space, in line with some previous research (Morency et al., 2011), the higher-income commuters demonstrated significantly larger activity space and higher likelihood of non-work participations than their Medium- and low-income peers. Among non-commuters, although the higher-income was also associated with larger activity space, the rate of non-work activities was not discernibly different across income groups.

The revealed effects of key variables suggest that MTR and bus might act differently in facilitating daily mobility of commuters and non-commuters, which was largely omitted in the previous research. For commuters, the availability of MTR stations appeared to reduce activity space, while the network accessibility increased it. On the other hand, positive and negative effects were found respectively for the availability of bus stops and network accessibility by bus. For non-commuters, the availability of MTR stations and bus stops was found to increase the size of activity space, while reverse was the case for network accessibility especially by bus. Despite such distinctions, a relatively consistent pattern emerged that the effects of the MTR accessibility variables were more pronounced among the higher-income than for the other groups, whilst the low-income's spatial extensiveness of activity space appeared to be affected mainly by bus accessibility.

Regarding non-work activity participation of commuters, transit accessibility appeared to serve as a marginal role. The effects of MTR accessibility were largely insignificant for participation maintenance activities, whilst significant effects were found for bus accessibility on discretionary activities mainly among the higher income group. For non-commuters, the modeling results indicated that transit accessibility (particularly the availability of MTR stations) might be more relevant in facilitating the non-work activities of the higher- and medium-income groups than for the low-income. Furthermore, it also appears that the effects of transit accessibility (both the availability of transit stations and network accessibility) were stronger on SDC than on non-activity participation, especially among commuters. This implies that better access to and by transit might materialize in reaching different locations, rather than more activity participation per se.

Overall, our findings basically confirmed our hypotheses, that the availability of and network accessibility by public transit appeared to be significantly linked to the spatial extensiveness of activity space of the higher-income commuters and non-commuters, and to a lesser extent, medium-income commuters. For the low-income, the availability of bus stops and network accessibility by bus appeared to play a more important role in their daily mobility. In this sense, particular attention can be given to better considering the travel needs of the low-income in arranging and planning bus services, e.g., enhancing the first and last mile experience of using bus service. Moreover, in line with previous research (Guzman & Oviedo, 2018; Tao et al., 2020), providing transit discount pass for the low-income who rely on MTR for daily travel may remain a valid option. At present, a Public Transport Fare Subsidy Scheme targeted at the low-income is being implemented across Hong Kong (MTR, 2019), which, we consider, shall be maintained and possibly improved to provide more targeted subsidy scheme (e.g., larger subsidy for the poorest group).

Our findings also indicate that a significant link existed between MTR accessibility and non-work activity participation, which tended to be more pronounced at the local level for the higher-income non-commuters, but less so among the low-income non-commuters. It suggests that enhancing the connection to maintenance and discretionary activity opportunities by MTR for the low-income may be worth considering to better accommodate their daily travel and activity needs. Potential measures may involve strengthening connection to more affordable daily-life facilities and services (e.g., grocery shops, health care) by MTR and concentrating more discretionary facilities in the vicinity of MTR stations.

To this end, the current study has contributed to the discourse on transit inequality by revealing the differentiated effects of transit accessibility on the activity space of different income groups. The empirical results are suggestive of a relatively pessimistic picture: that higher transit accessibility better facilitated the daily mobility and non-work activities of the higher-income groups (e.g., enabling better access to transit services and moving around better connected places) than for the low-income cohorts. As such, the tentative conclusion is that while most low-income residents might rely on public transit to remain socially active, they were less able to travel around well-connected places and utilize activity opportunities as the higher income. Accordingly, recommendations were proposed to improve the transit accessibility for the low-income. However, future research works are still needed to further capture the economic impacts of transit accessibility on the different dimensions of residential and daily mobility, with which, we expect, more surgical plans and strategies can be devised to help achieve more equitable transit systems.

There are four main avenues that future research may seek to advance the current study. First, the data employed only covered trips on a weekday. As such, we were unable to examine whether the effect of transit accessibility on activity space of different income groups might also vary across weekdays and weekends. It will be worth collecting travel survey data over continuous weekdays and weekends. Second, also due to data limitation, we did not actually test how the lack of economic resources and rise in housing price associated with transit service might create extra burdens for the low-income. Future research may seek to investigate these economic dimensions of transit inequality. Third, we were unable to take account of self-selection in the current study, which shall be addressed in future research that encompasses queries about the attitudinal dimensions of residents. Last, the TCS employed in the current study only contained records of mechanized trips, while walking trips were not provided in the data. Future research may look into this possibility and illuminate the potential trade-off between walking and mechanized non-work trips in TOD neighborhoods.

Acknowledgements

The authors thank the editors and anonymous reviewers for their constructive comments and suggestions. This research was supported by the Research Development Fund from the Worldwide Universities Network, the Strategic Partnership Award for Research Collaboration from the Chinese University of Hong Kong, and the Young Scholar Fund from Beijing Normal University (310421101).

Appendix

Appendix available as a supplemental file at www.jtlu.org/index.php/jtlu/rt/suppFiles/2075/0.

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