Paying for travel distance and time saving:

Transit fare and benefit mismatch and its justice implications

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Abstract

Transit fares affect not only whether people are not overburdened with their expenditure on transit services but also whether people can get reasonable benefits from transit services for what they pay. Prevalence of various simplified fare systems and highly differentiated service quality point to a plausible prima facie concern that transit riders suffer from transit fare and benefit mismatch (TFBM), evoking justice concerns and potential impacts on transit usage. This article enriches our understanding of justice implications of transit fares by proposing new metrics and testing them empirically in Hong Kong, where transit dependence is high, i.e., a considerable proportion of transit traffic is captive. By considering travel distance and time savings as primary benefits, two indexes are proposed to quantify TFBM. The distributional effects of TFBM on different neighborhood segments are compared and relationships between spatial or socio-economic vulnerability, TFBM, and transit usage are explored. Our findings suggest that the transit use ratio of neighborhoods in the peripheral areas of the city is significantly influenced by TFBM, while socio-economically vulnerable neighborhoods are less sensitive to TFBM. Due to the lack of available alternatives of motorized mode choice, socio-economically vulnerable neighborhoods face a higher risk of being impaired by TFBM.

Keywords: justice; transit fare and benefit mismatch; transit usage; Hong Kong

Introduction

The focus of studies on distributive justice in the transportation domain has been significantly shifted in the past two decades or so. Such focus was once on topics such as inequality of transport-related resources and investments (Currie 2010), exposure to transport-related externalities (Feitelson 2002), and observed daily travel behaviors (Banister 2018), whereas it has now been on inequality of transport accessibility (Martens 2016; Pereira et al. 2017). As "a primary good" required to live a decent life (Martens 2016 p.69) or "a human capability" to access to opportunities (Pereira et al. 2017 p.13), accessibility has been stressed and intensively examined in existing studies. However, academia has not given due attention to transit fares, which influence transit-based accessibility across space, time, and social groups. Indeed, equity and justice in transit accessibility cannot be achieved without creating a fair scheme of transit fares. Such scheme not only generates sufficient revenue to support operations and maintenance of transit systems but also partially encourages a modal shift from private car to transit (Redman 2013) and mitigates inequalities in access to opportunities (Sharaby and Shiftan 2012). In essence, the importance of transit fare fairness lies in the fact that equal access to various social and economic activities cannot be fully materialized if unfair or even prohibitive transit fares are in presence.

In perfectly competitive markets, transit fares are decided by the balance between transit supply and travel demand. However, in practice, environmental and congestion externalities, as well as the characteristics of transit industry such as public ownership and monopoly, cause market failures in transit services pricing, requiring interventions by the government (Estache and Gómez-Lobo 2005). These failures put people at risk of suffering from accessibility "poverty" and social exclusion. For instance, transit operators tend to serve affluent neighborhoods comparatively inelastic to fare hikes for higher and stable farebox revenue while having little economic incentive to provide enough services to minority neighborhoods that are elastic to fare hikes, even though the latter could more heavily depend on transit. Injustice might also emerge in joint development of transit and property, where cheap or even free transit services would favor high-end shopping malls rather than employers offering low-skilled and low-paying jobs. In reality, the former often cross-subsidize transit operators while it is often not the case for the latter.

To foster citizens' transit use habits, transport planners should pay more attention to transit users, especially the captive. Individuals, being price takers, make travel mode choices based on the tradeoff between cost and benefit. Transit riders always relate fares to services perceived/received (Redman 2013). In other words, transit riders are sensitive to possible transit fare and benefit mismatch (TFBM). Various patterns of transit fares, in line with highly differentiated transit service levels, point to a plausible prima facie concern that TFBM might be extremely severe sometimes and somewhere. These could influence both social justice and transit usage. This study intends to assess existing transit fares with quantitative TFBM criteria. It contends that transit fares should be in proportion to the corresponding benefits, either received or perceived. It does not aim to prescribe a specific way to arrive at equality and justice in transit fares, which could be context-sensitive. Instead, it aims to paint a big picture and elicit more meaningful discussions on spatial and social justice implications of transit fares and their impacts on transit usage.

A distributive justice approach can allow us to go beyond descriptive analysis of inequalities in TFBM (Pereira et al. 2017). Under the guidance of principles towards distributive justice, this study draws analyses on the impacts of TFBM on different neighborhoods to reveal whether current transit fares treat them equally or are substantially favor particular neighborhoods, and whether those favorably treated are vulnerable. It approaches the justice implications of TFBM by focusing on burdens of vulnerable neighborhoods. Based on spatial vulnerability and socio-economic vulnerability towards transit fares, vulnerable neighborhoods in this study refer to (a) neighborhoods in the peripheral areas of the city and (b) socio-economically vulnerable neighborhoods.

This study provides insights for urban/transport planners who aim to promote spatial and social justice in the transit realm. Specifically, it would (1) operationalize transit fare fairness with new indexes that are transferable across different contexts; (2) illustrate how spatial and socio-economic vulnerability of (potential) transit riders can be measured; (3) show how transit fares can have both spatial and social justice implications; (4) demonstrate how spatial or socio-economic vulnerability and transit fare inequality are related to transit usage.

Relevant Literature

In existing study, there are many inspiring theories of justice of relevance to the discussion and exploration on transportation equity and justice, which include Rawls' theory of justice, Dworkin's theory of equality of resources, and the capability approach (CA). These theories provide interesting yet sporadic answers to the fundamental questions of distributive justice: (1) What should be distributed? (2) Which principle should be used to guide the distribution? This section reviews the transportation equity literature on these theories of justice, elucidating justice principles and approaches for the distribution of transportation goods and services. Ultimately, a review on the justice implications of transit services pricing/fares in terms of assessment criteria and the underlying philosophical logic of distribution is presented.

Theories of justice

As an egalitarian, Rawls (1971) defined five types of primary goods (i.e., basic rights and liberty, freedom of movement and career choice, powers and prerogatives, income and wealth, and self-respect) and established three principles (i.e., greatest equal liberty, fair equality of opportunity, and difference principle ordered by priority) to guide the distribution of primary goods. The difference principle is used to distribute income and wealth. The inequalities in income and wealth are considered fair as long as they are derived from fair equality of opportunity and free choice, whereas they are unfair if they result from morally arbitrary factors. The difference principle suggests that the justification of the policy alternatives should be based on the maximin criterion, that is, the chosen alternative should maximize the benefit of the least-advantaged groups, to mitigate the possible worst outcome brought by morally arbitrary factors, thereby reducing the inequality of opportunity. Rawls (2001) broadened the primary goods of income and wealth by incorporating public goods and services provided by the government such as health care. Researchers who followed Rawls' theory believed that the difference principle applies to transportation goods and services, accessibility, and of course, transit fares (Van Wee and Geurs 2011; Van Wee and Roeser 2013; Pereira et al. 2017; Lucas et al. 2016).

The capability approach (CA) contends that it is human capabilities rather than primary goods that should be centered in the reasoning of justice (Sen 2009). Nussbaum (2011) defined human capabilities as individual freedom and opportunities to achieve the ends that they value and described human capabilities as "combined capabilities" because individual freedom and opportunities are closely related to personal capabilities and the political, social, and economic environment. The CA upholds that individuals should be provided sufficient basic goods and services so that they have “basic capabilities” (Sen 2009; Nussbaum 2011). Among the ten “basic capabilities” by Nussbaum (2006) is the freedom of movement, which can be realized by the provision of transport goods and services. Sufficient accessibility and affordable transit fares provide the freedom and opportunities for individuals to move about.

Unlike the above theories, Dworkin (1981a, 1981b, 2002) suggested resources be the metric of fairness. To achieve equality of resources, Dworkin developed a complex line of reasoning by employing two approaches from economic markets. Individuals are assumed to possess equal “wealth” at the outset. An auction approach enables them to purchase a bunch of equivalent goods, the actual values of which are reflected by both popularity and scarcity. Then, a hypothetical insurance approach enables individuals to mitigate some forms of brute bad luck by setting up the bottom line of a specific resource. This indicates the level of compensation that people would like to ensure if impairments, limited skills and talents, insufficient transport accessibility, transit fare unaffordability, or others strike. Dworkin’s theory is featured by both egalitarian and sufficientarian concerns. It not only adheres to equality of resources via an auction approach but also advocates the minimum level of treasurable resources via an insurance approach.

Distributive justice in transportation

Justice (also called “equity” and “fairness” by scholars at times) in transportation is conceptualized as the fair distribution of benefits and costs in the transportation domain(Sanchez 2007). With an increased social awareness of justice worldwide, researchers and policy analysts have picked up theories of justice and used them to enlighten justice-related scholarship and practices in the domain of transportation. The main challenge faced by them is employing proper justice principles and approaches for the distribution of transportation goods and services. However, whether certain justice principles and approaches can lead to a fairer distribution in transportation is still open-ended (Martens 2012).

The latest transportation equity literature has shown a shift from Pareto and utilitarianism to egalitarianism and sufficientarianism. The classic Pareto-improvement principle, which aims at Pareto efficiency (or Pareto optimality), justifies benefit increments for anyone as long as the change does not make others worse off (Juran, 1950). Such Pareto improvement can be achieved even if the most vulnerable do not benefit or lose while the least vulnerable receive the most benefits. In this scenario, existing inequalities would worsen (Martens and Golub 2018). Traditional transportation planning adopting the appraisal method of cost-benefit analysis (CBA) is rooted in the philosophy of utilitarianism, which advocates the greatest utility for the majority of people. However, the utilitarian approach is increasingly criticized for strict consequentialism and overlooking individual rights (Van Wee and Geurs 2011; Van Wee and Roeser 2013; Lucas et al. 2016; Pereira et al. 2017).

More or less, egalitarian and sufficientarian approaches are two of the most promising approaches that can be used to address the issues of transportation inequality and poverty, respectively. While egalitarianism holds that people should be treated equally, sufficientarianism suggests that everyone should be assisted to reach a sufficient level so that their basic needs can be fulfilled (Van Wee and Geurs 2011; Lucas et al. 2016).

The potential of justice theories that contain sufficientarian and/or egalitarian elements for promoting justice in transportation is intensively explored recently. Following Walzer's spheres of justice approach, which argues that goods with a distinct social meaning should be treated separately and be distributed by an internal reasoning (Walzer 1983), Martens (2012) and Martens et al. (2012)

explored the social meaning of transportation goods and identified accessibility as the benefit of transportation that deserves a separate and institution-led distribution. After clarifying principles derived from Rawls's theory of justice, they concluded that the maximax principle (i.e., maximizing the average access level with a range constraint) is the most applicable principle for the distribution of accessibility. Later, mainly built on Dworkin's theory of equality of resources, Martens (2016) regarded transportation goods as resources and argued that "a transportation system is fair if, and only if, it provides a sufficient level of accessibility to all under most circumstances" (p. 215).

Similarly, the CA suggests that a sufficient level of accessibility is a prerequisite for guaranteeing a sufficient level of basic capabilities (Nahmias-Biran et al. 2017). Based on a combination of Rawls' distributive principles and CAs' conceptualization of human capabilities, Pereira et al. (2017) established grounds for the justification of transportation policies and distribution of accessibility: (a) transportation policies should never violate or sacrifice individual basic rights and liberties; (b) transportation investments and services should prioritize vulnerable people, thereby reducing inequality of opportunities; (c) a minimum level of transportation accessibility to key destinations should be set according to a given society's history, values, and wealth conditions.

With recognized importance of accessibility in seeking transportation justice , efforts have been made to measure accessibility more comprehensively. El-Geneidy et al. (2016) upgraded existing travel time-based accessibility measures by factoring in travel expenses. Moreover, travel demand modeling approaches were used to measure comprehensive accessibility (e.g., generalized transport costs and consumer surplus) (Koopmans et al. 2013; Bills and Walker 2017). Nevertheless, such accessibility measures emphasize the outcome of integrating personal abilities, transportation systems, and land use patterns, but do not shed light on designing fair transit fares. A sufficient level of accessibility cannot be achieved without a fair scheme of transit fares.

Justice implications of transit services pricing

The literature has intensively discussed the applicability of various theories of justice in the transportation domain, which has inspired transportation finance and pricing. Taylor and Norton (2009) created a three-by-three matrix with three analysis units (i.e., geographic units, social groups, and individuals) and three types of equity (i.e., market, opportunity, and outcome). Indeed, assessing social and spatial justice in transit services pricing is a complex task that involves two other key and interrelated components: the assessment criteria and the philosophical logic of distribution.

Nuworsoo et al. (2009) proposed three assessment criteria: the cost, the benefit, and the ability to pay. The cost criterion requires transit riders to pay for transit services according to (average or marginal) costs of providing such services. To meet the benefit criterion, transit riders should be charged in proportion to the benefit they receive. The ability to pay criterion suggests fares be sensitive to and account for transit riders' income and wealth.

Studies on equity implications of transit fares can be categorized into two camps according to the philosophical logic of distribution: horizontal equity, which advocates that transit riders with comparable need and ability should be treated equally and should "get what they pay for and pay for what they get" (Litman 2002, p. 4); and vertical equity, which underlines that equitable transit pricing policies should favor economically and/or socially vulnerable people as well as those with mobility impairments (Litman 2002).

Bandegani and Akbarzadeh (2016), using the cost criterion, compared the equity impacts of a distance-based fare structure and a flat fare structure along the horizontal dimension. The marginal cost pricing method is proposed to efficiently maximize transit agencies' fare revenues (Jansson 1979; Jansson and Angell 2012; Kaddoura et al. 2015; Martens 2016). But it does not consider the heterogeneous benefits that transit riders receive and their varying abilities to pay.

Many studies were more concerned with transit riders' benefit and their affordability from the vertical dimension. Following the seminal work by Cervero (1981), the equity impacts of replacing existing fares with distance-based fares on different social groups and spatial units were assessed (Farber et al. 2014; Zhao and Zhang 2019). Zhou et al. (2019) examined the equity and spatial implications of transit fares using fare per kilometer as a criterion in the context of Brisbane, Australia. Moreover, an affordability index was established by Zhao and Zhang (2019) to measure the cost burden of metro users in a transition from flat fares to distance-based fares. The equity impacts of other transit fare structures (e.g., zone-based fare structure) and alternative transit fare schemes (e.g., fare hikes and fare reductions) were also discussed (Nuworsoo et al. 2009; Nahmias-Biran et al. 2014). However, according to our best knowledge, no scheme of transit fares can well consider all possible dimensions of justice.

Summary of the literature reviewed

In summary, theories of justice such as Rawls' theory of justice, Dworkin's theory of equality of resources, and the capability approach (CA) provide systematic reasonings for a fairer distribution of transportation goods and services. Existing transportation equity literature considers accessibility as the basic element in seeking transportation justice. This cannot be achieved without a fair scheme of transit fares. Our review on justice implications of transit services pricing justifies the assessment of transit fares considering both the benefits received/perceived and ability to pay along the vertical dimension. Existing studies suggest that the distance-based fare structure can better capture the varying benefits that transit riders receive when compared with other transit fare structures (Cervero 1981; Farber et al. 2014; Zhao and Zhang 2019). However, based on our knowledge and experience, most existing transit fares are not fully linked to the benefits. Therefore, a desirable transit fare scheme that matches the benefits is necessary. The ability to pay criterion, which is rooted in Rawls' difference principle and Dworkin's hypothetical insurance approach pertaining to sufficientarianism, calls for attention to burdens of vulnerable people.

Methodology

The site

Hong Kong is a dense city with a population of more than 7.5 million and a land area of 1,104 square kilometers (426 square miles) and is located on the eastern side of Pearl River estuary in southern China (Census and Statistics Department of Hong Kong 2019). Hong Kong has proactively adopted transit-oriented policies, which enables the local transit system to carry over 90% of daily trips. Transit services in Hong Kong are operated on a commercial basis, i.e., private or semi-private parties own and operate transit services in pursuit of profits whereas the government takes regulatory and overseeing responsibilities for route design and services pricing (Transport Department of Hong Kong 2017).

Hong Kong's transit system is multimodal, including heavy rail, light rail, franchised buses, non-franchised buses, light buses, trams, taxis and ferries. Heavy rail is the backbone while light rail plays an important role in the Northwest New Territories. Other than railways, franchised bus is another mass transit carrier that not only serves areas inaccessible by railways but also provides feeder services to railways. Other modes play supplementary roles (Transport Department of Hong Kong 2017). This study focuses on franchised buses and railways that are operated on fixed fares stipulated by the local transport department. They account for approximately 50 percent of local daily transit trips (Transport Department of Hong Kong 2017).

There are three transit fare schemes in Hong Kong. Most franchised buses (referred to as "buses" for short hereafter) adopt flat fares or section-based fares while railways employ distance-based fares. As shown in Fig. 1, for a transit route with three stations A, B, and C, fares can vary across these schemes. Section-based fares depend on where passengers board. Flat fares are identical no matter where passengers board and alight. Distance-based fares are determined by distance. Apparently, these distinct schemes of transit fares result in a substantial mismatch between fares and travel distance. Flat fares, for instance, charge the same for trips with different distances, while section-based fares may even charge less for longer trips in the same section. In contrast, distance-based fares are more desirable. Considering substantial differences between bus fares and railway fares as well as the fact that railway can only serve limited urban areas, the following analyses are conducted on modes of bus and bus+railway, respectively.

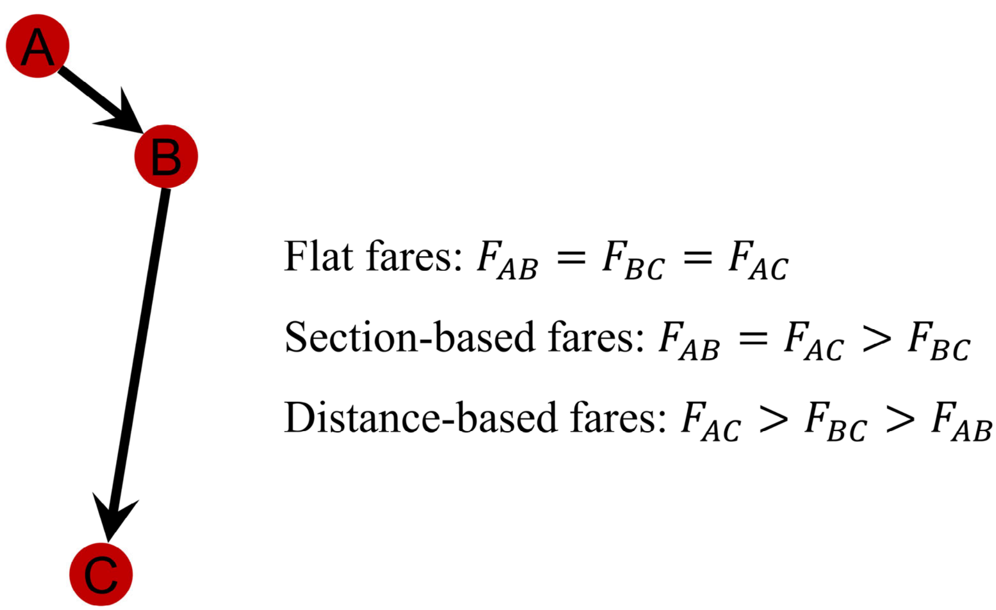

Fig. 1. Three typical patterns of transit fares.

Data and analysis unit

The 2011 Population Census data were collected by the Census and Statistics Department of Hong Kong and were presented in a multi-level demarcation system (i.e., Primary Planning Units (PPUs) - Secondary Planning Units (SPUs) - Tertiary Planning Units (TPUs) - Large Street Block Groups (LSBGs)). This study uses the LSBG as analysis unit to support fine-grained analyses. 240 LSBGs, which account for about 20% of the total, are randomly selected as research samples by a stratified sampling method based on nine PPUs with three outlying islands excluded (Fig. 2 top).

According to the 2011 Population Census, only 17% of the employees worked and resided in the same district (Census and Statistics Department of Hong Kong 2011). The employment activities were concentrated in areas such as Central, Tsim Sha Tsui, Wanchai, and Yau Tsim Mong (Development Bureau and Planning Department, Hong Kong 2016). As shown in Fig. 2 (top), three meaningful key destinations are identified including two existing CBDs (i.e., Central and Tsim Sha Tsui) and one future CBD (i.e., Kai Tak Development) proposed in the "Hong Kong 2030+: Towards a Planning Vision and Strategy Transcending 2030".

The Baidu Map Application Programming Interface (Baidu Map API), based on the road network and real-time traffic, provides route planning services for users. Once origin, destination, and travel mode(s) have been given, the Baidu Map API will return recommended routes and relevant information about the routes. With a python program, information was automatically collected from the Baidu Map API regarding routes from centroids of the selected LSBGs to the key destinations on modes of bus and bus+railway, respectively. The route information includes transit travel distance, transit travel time, boarding station, alighting station, and travel modes. Transit travel time contains estimated in-vehicle time, waiting time, and transfer time. Due to the absence of fare information in the Baidu Map, we manually collected adult fare information for the recommended transit routes through a mobile application named HKeMobility. The descriptive statistics of transit route data are presented in Table 1.

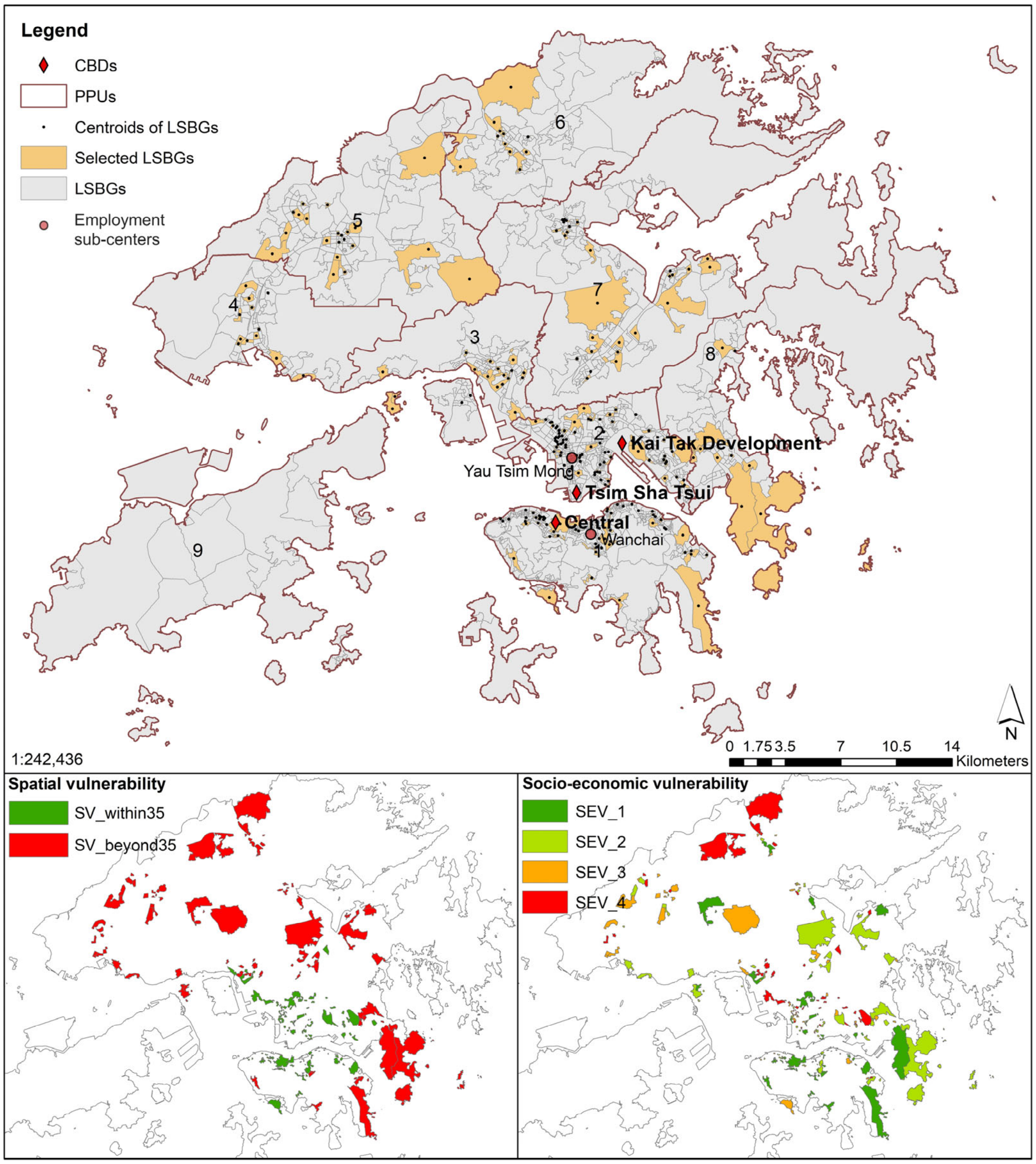

Fig. 2. Selected LSBGs and key destinations (top); Neighborhood segments based on spatial vulnerability and socio-economic vulnerability (bottom).

Transit Fare and Benefit Mismatch (TFBM) indexes

Noted that different factors can contribute to TFBM, a methodology for designing a desirable transit fare scheme that matches the benefits that transit riders receive and measuring TFBM is required.

As argued by Redman (2013), transit riders are sensitive to how much benefits they receive or perceive and how well they are actually served once they have paid. Only when travel expenditures match not only quantity (e.g., travel distance) but also quality (e.g., in-vehicle time, waiting time, transfer time, access/egress times, and in-vehicle comfort) of transit services can riders get what they paid for and are willing to pay for what they got. The saving of travel time affects transit riders' perceptions of transit quality and could potentially influence transit usage. A survey on the new Los Angeles Metro Orange Line showed that the line reduced perceived travel time of most passengers who just switched to it. Subsequently, the line experienced a substantial increase in ridership (Pucher et al. 2005). Travel distance reflects how much services a transit rider receives, and the saving of travel time approximates how good the services are. Therefore, we used travel distance and travel time saving as proxies of quantity and quality of transit services to reflect the benefits that transit riders receive.

Theoretically, distance-based transit fares are formulated as

$$F_i^D = f_0 d_i \tag{1}$$

where F_i^D is distance-based transit fare for trip i, f_0 is reference fare per kilometer, d_i is network-based travel distance in kilometers for trip i.

The equity value of travel time savings rather than the market-based value can be used to formulate time-saving-based transit fares (Hayashi and Morisugi 2000; Mackie et al. 2001). A transit route that is faster is supposed to be more expensive than others, ceteris paribus. More precisely, for transit trips with identical lengths, the fares should account for the amount of time saved: the more the time saved, the higher the fares. In this respect, a distance-based transit fare scheme does not always coincide with a time-saving-based transit fare scheme. Therefore, time-saving-based transit fares are formulated as

$$F_i^T = f_0 d_i + a(t_0 d_i - t_i) \tag{2}$$

where F_i^T is time saving-based transit fare for trip i, f_0 is reference fare per kilometer, d_i is travel distance in kilometers for trip i, t_0 is reference travel time per kilometer, t_i is actual travel time for trip i, thus, $t_0 d_i - t_i$ represents the amount of time saved for trip i, a is monetary value of one minute's saving, which is city-specific, group-specific, and even individual-specific.

In order to measure TFBM by comparing existing transit fares with the desirable ones, it is necessary to introduce a reference fare, which consider both travel distance and travel time saving. Such reference should be city-specific because it is inappropriate to share the same transit fare scheme across contexts with different transit service levels, financial conditions, and cultures. For a given city, the whole transit fare system is generally stable and balanced. This study considers the citywide average as fair and further investigations are based on this average. Specifically, f_0, the average fare per kilometer across the whole transit system in question, is supposed to be the reference fare and it matches t_0, the average travel time per kilometer, i.e., the corresponding reference for travel time. Then, in a transit system with n trips, the reference fare per kilometer and the reference travel time per kilometer would be $f_0 = \sum_{j=1}^{n} f_j / \sum_{j=1}^{n} d_j$, and $t_0 = \sum_{j=1}^{n} t_j / \sum_{j=1}^{n} d_j$ respectively.

Accordingly, the fare and distance mismatch index ($FDMI$) can be formulated by dividing the actual fare f_i by the theoretical distance-based fare F_i^D for each trip i:

$$FDMI_i = \frac{f_i}{\frac{\sum_{j=1}^{n} f_j}{\sum_{j=1}^{n} d_j} \times d_i} \quad (3)$$

However, measuring the fare and time saving mismatch index ($FTMI$) cannot be straightforward because there is an unknown variable a in the formula of time saving-based fare F_i^T. Given there exist differences between cities, it would be inappropriate and out of the scope of this study to identify a universal absolute monetary value of travel time saving that holds for all cities. Nevertheless, our goal can also be achieved by measuring how money-consuming and time-saving the trip is. Based on the degree of money consuming (calculated by $f_i/(\sum_{j=1}^{n} f_j/\sum_{j=1}^{n} d_j \times d_i)$) and the degree of time saving (calculated by $(\sum_{j=1}^{n} t_j/\sum_{j=1}^{n} d_j \times d_i)/t_i$) for transit trip i, a two-by-two matrix emerges (see Fig. 3-A). Trips that are money-consuming and time-consuming (I) are considered overpriced while trips in the opposite situation (IV) are considered underpriced. Desirable fares exist in the other two categories of trips (II and III). To match transit fare and time saving, the degree of money consuming should be in proportion to the degree of time saving. The $FTMI$ is formulated as

$$FTMI_i = \frac{f_i \times t_i}{\frac{\sum_{j=1}^{n} f_j}{\sum_{j=1}^{n} d_j} \times d_i \times \frac{\sum_{j=1}^{n} t_j}{\sum_{j=1}^{n} d_j} \times d_i} \quad (4)$$

$FDMI$ and $FTMI$ are represented by the slopes of lines in Fig. 3-B and Fig. 3-C, respectively. For both of them, the larger the index, the greater the degree of overpricing. The smaller the index, the greater the degree of underpricing. The closer the index is to 1, the more equitable the fare is.

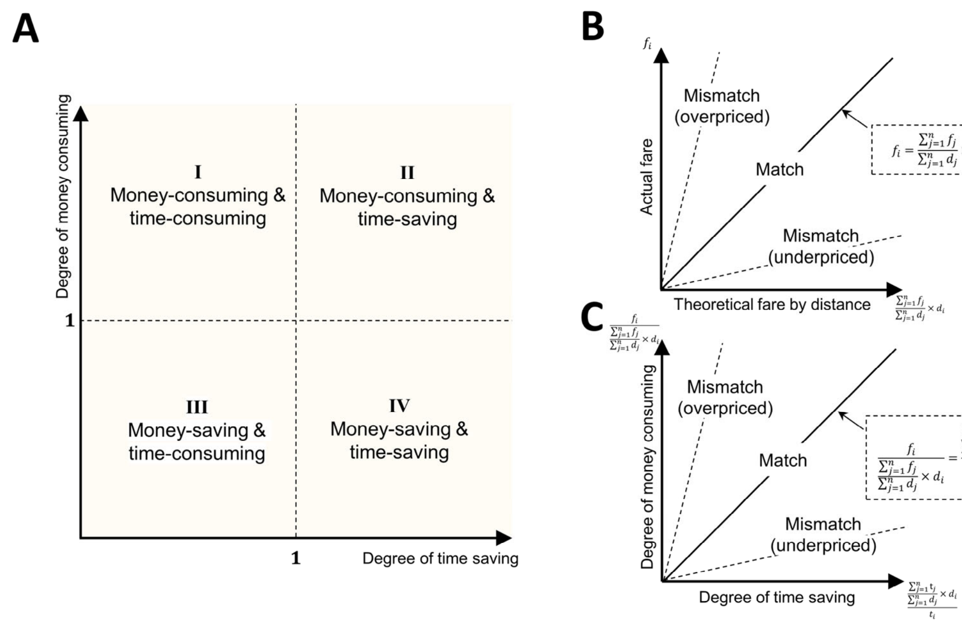

Fig. 3. TFBM indexes.

Spatial vulnerability and socio-economic vulnerability towards transit fares at neighborhood level

The theory of travel time budget suggests that the total amount of time spent on traveling per person per day is stable, remaining at around 70 minutes (Ahmed 2014). The generalized expenditure on transportation per person per day, which consists of both time and money, is also quite stable (Goodwin, 1981). A spatial factor that influences a person's travel time could affect his/her vulnerability towards transit fares. Therefore, to reflect spatial vulnerability towards transit fares, a variable concerning whether people can access the key destinations within 35 minutes (assuming that most people spend 70 minutes on a round trip) is used to group the selected LSBGs into two segments: $SV\_within35$ and $SV\_beyond35$.

A set of socio-economic variables that could affect a person's ability to pay transit fares are identified partially based on Manaugh and El-Geneidy (2012) and El-Geneidy et al. (2016) and partially based on our local knowledge. In addition to household income, mortgage payment, loan payment, and rent are also incorporated as they constitute a great proportion of the local household expenditure. It is worth mentioning that since there are special fare concessions for the elderly, children, and eligible students, the factor of age is not considered. We focus on adult fares only in this study. The socio-economic vulnerability index for LSBG s, which belongs to the LSBG set S, is denoted as V_s and consists of the following equally weighted variables:

MHI_s: Median household income (divided by the average household size) for s.

$INC - MOR_s$: Median differences between income and mortgage and loan repayment for s.

$INC - REN_s$: Median differences between income and rent for s.

V_s is formulated based on the above normalized variables:

$$SEV_s = 1/(\frac{MHI_s}{max_{s\in S}MHI_s} + \frac{INC-MOR_s}{max_{s\in S}INC-MOR_s} + \frac{INC-REN_s}{max_{s\in S}INC-REN_s}) \quad (5)$$

To reflect socio-economic vulnerability towards transit fares, the selected LSBGs are grouped into four segments: SEV_1, SEV_2, SEV_3, and SEV_4.

The spatial distribution of all the segments is presented in Fig. 2 (bottom). $SV\_within35$ cluster in the central area and $SV\_beyond35$ are in the peripheral area. In contrast, the segments categorized by socio-economic vulnerability seem to be randomly distributed.

Results and Discussions

Measuring TFBM with FDMI and FTMI

The TFBM for transit trips between the selected LSBGs and the key destinations on modes of bus and bus+railway is measured and presented in Table 2 (also see Fig. S1 in the Supplemental Materials). We observed that bus+railway trips tend to have higher $FDMI$ and lower $FTMI$ than bus trips. This is mainly due to the fact that bus+railway trips (represented by orange diamonds in Fig. 4-top) are generally more money-consuming and are much more time-saving when compared with bus trips (represented by blue points in Fig. 4-top). Table 2 also underlines that $FTMI$ values are generally larger than $FDMI$ values, indicating a severer mismatch between transit fares and quality of transit services. Besides, $FDMI$ and $FTMI$ are highly and positively correlated as shown in Fig. 4-bottom. This implies that a transit rider overpaying for the distance traveled is likely to overpay for the time saved.

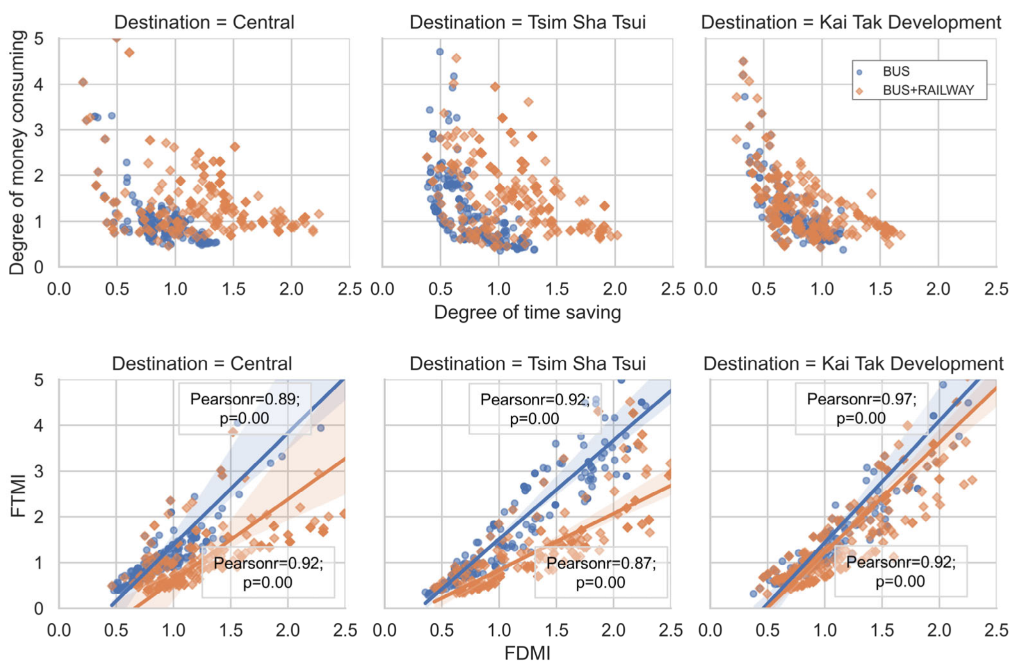

Fig. 4. Degrees of time saving and money consuming on modes of bus and bus+railway (top); Pearson correlation between *FDMI* and *FTMI* (bottom).

Trends of TFBM by neighborhood segments

An evaluation of distributive justice of transport policies requires a revelation of their distributional effects on different population groups, the most vulnerable group in particular. In this subsection, we revealed the distributional impacts of TFBM on different neighborhoods and assessed the existing transit fares by paying attention to the burdens of vulnerable neighborhoods.

Box plots in Fig. 5 present TFBM scores for the neighborhood segments grouped by spatial vulnerability, i.e., neighborhoods in the central areas accessible from the key destinations within 35 minutes ($SV\_within35$) and neighborhoods in the peripheral areas inaccessible from the key destinations within 35 minutes ($SV\_beyond35$), respectively. We observe a pattern that the neighborhoods in the peripheral areas have lower TFBM scores than the neighborhoods in the central areas. This suggests that the neighborhoods in the central areas suffer from severer overpricing of transit services than the neighborhoods in the peripheral areas, assuming that all of them go to the CBDs in the same quantity. In other words, citizens living closer to the city center are more likely to overpay for transit services. However, looking at this in another way, their mobility needs can be satisfied more easily within the travel time budget (70 mins) mentioned above. Moreover, they are more likely to enjoy higher accessibility to various facilities and opportunities by walking and might not even need to use transit as frequently as those living in the peripheral areas. For the neighborhoods in the peripheral areas, given that the generalized expenditure is stable, a perception of transit fare underpricing may encourage a modal shift from private car to transit.

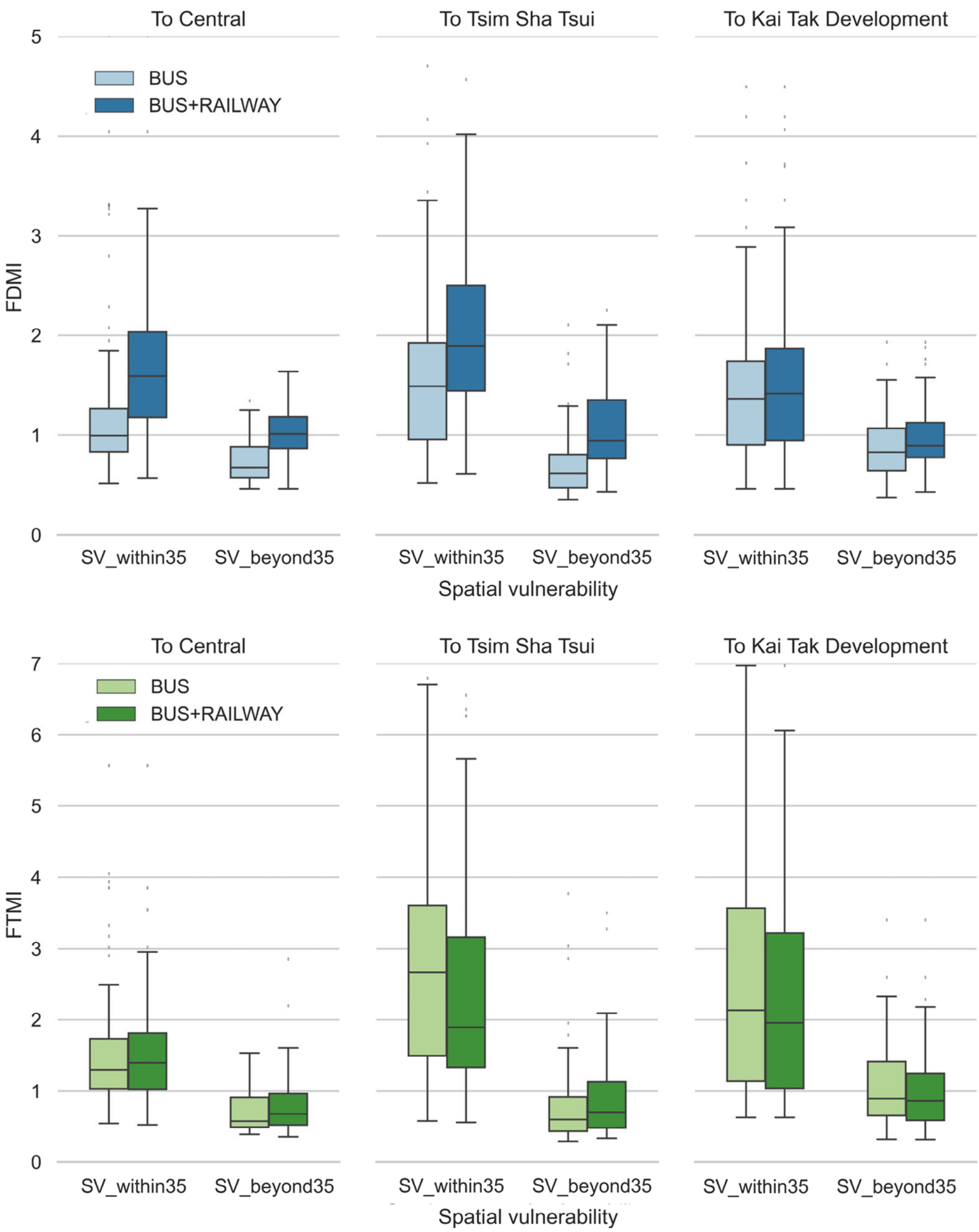

Fig. 5. Box plots of *FDMI* and *FTMI* among spatial neighborhood segments.

TFBM scores for the neighborhood segments ranging from SEV_1 (the least socio-economically vulnerable segment) to SEV_4 (the most socio-economically vulnerable segment) are compared and whether the vulnerable neighborhoods are prioritized is examined through box plots in Fig. 6. In general, $FDMI$ and $FTMI$ exhibit similar patterns across the neighborhood segments. Specifically, the scores decrease from the least socio-economically vulnerable (SEV_1)

to others for transit trips to the existing CBDs, i.e., Central and Tsim Sha Tsui. Meanwhile, the most socio-economically vulnerable (SEV_4) enjoy a comparable level of scores with the two less vulnerable (SEV_2 and SEV_3). As for transit trips to the planned CBD, i.e., Kai Tak Development, the scores of the most socio-economically vulnerable (SEV_4) are remarkably higher than those of others. These findings suggest that the most socio-economically vulnerable would at least not face a severer overpricing of transit services than other neighborhoods when traveling to the existing CBDs if travel frequency is not considered. However, these neighborhoods would have to pay more for transit-related benefits than others when traveling to the planned CBD by transit. Thus, measures such as reduced fares or express routes should be introduced if we aim to provide more equitable transit services to and from the planned CBD, which could induce a greater number of transit trips than today. In general, considering that transit trips to and from the planned CBD are still scarce at present, the existing fares seem to favor the most socio-economically vulnerable neighborhoods.

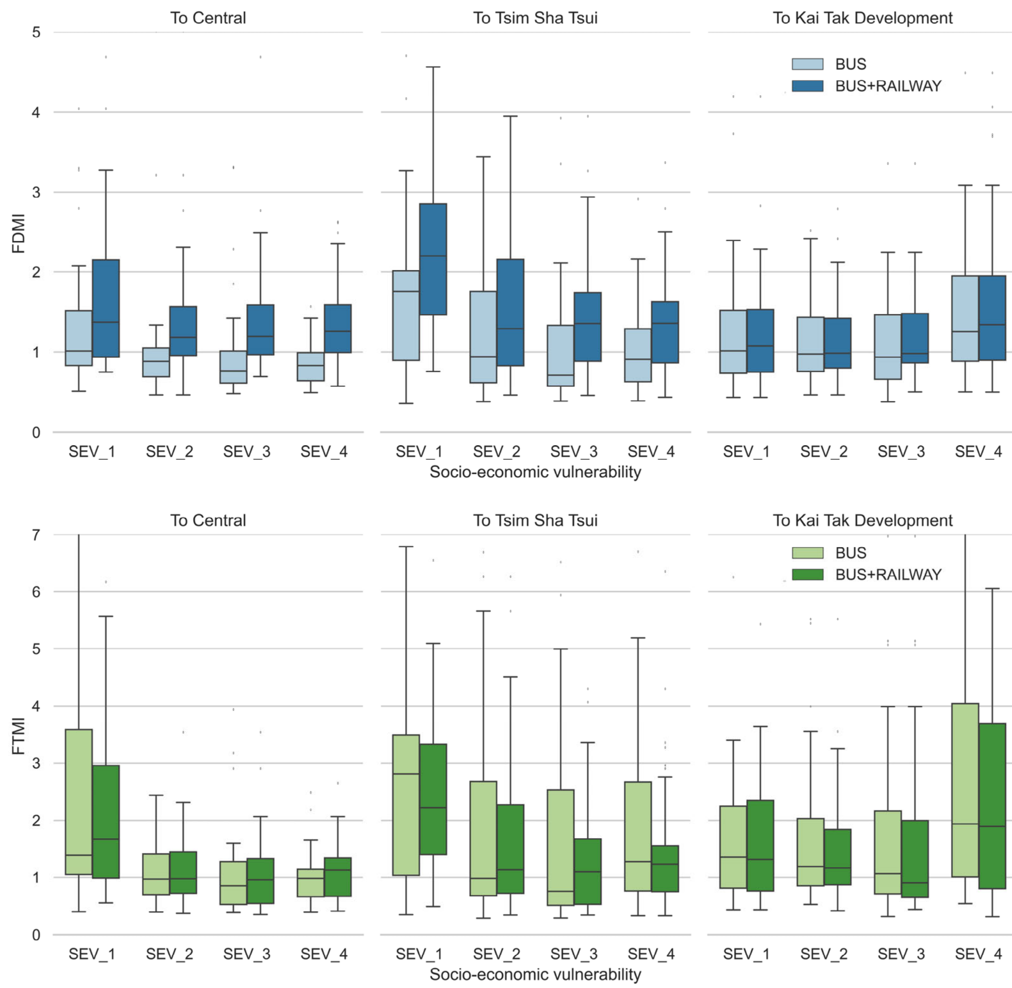

Fig. 6. Box plots of *FDMI* and *FTMI* among socio-economic neighborhood segments.

Nevertheless, there are vulnerable neighborhoods that are highly dependent on transit and might have to frequently bear with high TFBM. Therefore, we cannot rush into conclusions without further discussions on travel behaviors of various neighborhoods. This would require further investigations on whether such vulnerable neighborhoods are more frequently impacted by TFBM. Looking into the relationships between vulnerability, TFBM, and transit usage would provide us with more clues.

Relationships between vulnerability, TFBM, and transit usage

Although the distributional impacts of TFBM on different neighborhoods have been revealed above, how spatial or socio-economic vulnerability and TFBM are related to travel behavior needs to be investigated further. The Pearson correlation analyses (see Fig. S2 in the Supplemental Materials) suggest that socio-economic vulnerability is positively correlated to transit usage, with Pearson correlation coefficients of 0.34 for bus use ratio and 0.61 for bus+railway use ratio. The Pearson correlation analyses also show that TFBM and transit usage are negatively and weakly correlated, with their Pearson correlation coefficients falling in the range of -0.33 to -0.20.

A series of descriptive analyses and t-tests are designed in an attempt to examine and compare the sensitivity to TFBM between the least and most vulnerable neighborhoods. Considering that combining modes of bus and railway is more common and popular, and that the existing CBDs are more attractive than the planned one at present, the descriptive analyses and t-tests are based on the bus+railway trips to and from the existing CBDs. The results are presented in Table 3 (also see Fig. S3 in the Supplemental Materials for graphic description). From the perspective of spatial vulnerability, both the least vulnerable ($SV\_within35$) and the most vulnerable ($SV\_beyond35$) show that the neighborhoods with lower TFBM have significantly higher transit use ratios than those with higher TFBM. However, such disparity is less remarkable for the former, i.e., the neighborhoods in the central areas. One possible explanation is that given fixed travel time and money budget, people living closer to the city center may have a greater tolerance for transit fare overpricing because they can access the key destinations in less time. They rely more heavily on transit even if they may have to overpay for transit services. In contrast, people living in the peripheral areas are more sensitive to TFBM. Longer travel time decreases their tolerance for overpriced transit fares.

From the perspective of socio-economic vulnerability, only the least vulnerable (SEV_1)

exhibits significant differences in transit usage between the neighborhoods enjoying lower TFBM and those suffering from higher TFBM. In contrast, the most vulnerable (SEV_4) seem to display a high level of transit use ratio even if they suffer from higher TFBM. Higher TFBM could not reduce the socio-economically vulnerable riders' willingness to use transit. Our finding indicates that socio-economically vulnerable riders are less sensitive to TFBM. This leads to a reasonable speculation that, when suffering from higher TFBM, the least vulnerable people might always have another option, e.g., private car, while the most vulnerable people have no alternative but to overpay for transit services.

Conclusions

Studies on distributive justice implications of transit fares are quite limited. This article shows how transit fares can have both spatial and social justice implications and how spatial or socio-economic vulnerability and transit fare inequality are related to transit usage. Based on an empirical study of Hong Kong, we achieved something interesting and even transferrable to other contexts.

First, we proposed two indexes (i.e., $FDMI$ and $FTMI$) to measure TFBM.

Second, we measured spatial vulnerability and socio-economic vulnerability at neighborhood level.

Third, we revealed the distributional impacts of TFBM on different neighborhood segments. Our findings suggest that neighborhoods in the central areas are more likely to overpay for transit services when traveling by transit. The most socio-economically vulnerable neighborhoods tend to enjoy underpriced transit services when compared with the least socio-economically vulnerable neighborhoods.

Fourth, we investigated how spatial or socio-economic vulnerability and TFBM are related to transit usage. The results indicate that the least and most vulnerable neighborhoods respond differently to TFBM. The neighborhoods in the peripheral areas are more sensitive to TFBM than the neighborhoods in the central areas. However, the socio-economically vulnerable neighborhoods can hardly stop using transit even if they overpaid for transit services (Cervero, 1990). In other words, the socio-economically vulnerable neighborhoods face a higher risk of being impaired by TFBM.

Urban/transportation planning, as a means of public intervention to articulate and achieve a collective vision of the future city, should incorporate justice concerns (Zapata and Bates 2015). Despite that some findings and insights offered by this study might be specific to the local context, others still have general implications for pursuing equitable urban/transportation planning. First, this study translates the fairness goal in transit pricing into a clearly specified objective (i.e., matching transit fares with the benefits that transit riders receive) and operationalizes this objective with two proposed indexes. The indexes can be integrated into urban/transportation planning as technical assessment tools for better considerations for transportation equity.

Second, this study calls on urban/transportation planners to carefully formulate targeted strategies on spatially and socio-economically vulnerable neighborhoods suffering from transit fare inequity. Urban/transportation planners can adapt the methods and procedures this study proposed to identify such neighborhoods in their own cities. This research is based on official street-block level data, analogs of which are usually available across places/contexts. In the US, for instance, the census has the Transportation Planning Package, which can be used to replicate what is done in Hong Kong.

Various fare concession schemes for vulnerable groups (e.g., the elderly) have also been formulated to promote transportation justice and reduce opportunity inequality. Free fare schemes seem to be fair because they do not add inequalities to the existing transit accessibility measured in time. However, such schemes could cause a substantial increase of disruptive and annoying riders and aggravate the riding environment (Redman 2013). Therefore, distributive justice cannot be achieved by simply adopting a free fare scheme.

There is a long way to go before we can fully understand what (transit fare) justice means in the transportation domain, what justice can do to ensure a minimum level of transit accessibility across groups, and what justice can do to promote desirable travel behaviors. This study has several limitations that can be treated as starting points for future research. First, the proposed transit fare fairness indexes only consider distance traveled and time saved, whereas the benefit that transit users receive is more than that and it involves multiple parties such as transit users, officials, operators, and legislators. Future research should formulate more transit fare fairness metrics that account more fully for the interests of more parties.

Second, we based our analyses on simplified travel patterns, i.e., traveling from centroids of street blocks to the key destinations. But in reality, travel behaviors could be quite complicated. Looking forward, usage of smartcard data in analyzing people's transit usage, fare paid, distance travelled, and time spent might help us improve in this regards.

Third, we used aggregated census data at neighborhood level instead of disaggregated data. Variations in people's capability to use transit services, people's tradeoffs between money and time, and people's preference for different travel modes are absent in aggregated data. In fact, places like Hong Kong often provide multiple alternatives so that people can make different choices. Future research requires better consideration of the availability of potential choices and individual affordability and preference. These gaps will be filled through questionnaires in the future.

Data Available Statement

All data used during the study appear in the submitted article.

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Tables

Table 1. Descriptive statistics of transit route data

	Routes on bus			Routes on bus+railway		
	Average travel distance (km)	Average travel time (min)	Average fare (HKD)	Average travel distance (km)	Average travel time (min)	Average fare (HKD)
To Central	16.23	42.42	14.15	14.07	27.72	17.68
To Tsim Sha Tsui	13.52	40.23	12.73	12.54	26.62	16.14
To Kai Tak Development	14.11	43.68	14.40	14.34	38.5	15.76
Number of routes		720			720	

668

669 **Table 2.** Descriptive statistics of TFBM

Mean (SD)	Bus trips			Bus+railway trips		
	To Central	To Tsim Sha Tsui	To Kai Tak Development	To Central	To Tsim Sha Tsui	To Kai Tak Development
FDMI	1.22 (1.50)	1.28 (1.01)	1.30 (1.28)	1.60 (1.79)	1.63 (0.88)	1.28 (0.68)
FTMI	2.25 (4.13)	2.24 (3.24)	2.32 (4.48)	2.17 (5.58)	1.78 (2.54)	1.97 (2.10)

670

671 **Table 3.** Descriptive statistics and t-test results of the least and most vulnerable neighborhoods

with low and high TFBM scores

Vulnerability dimension	**Neighborhood segment**	**Transit use ratio Mean (SD)**		**t-test sig. (2-tailed)**
Spatial vulnerability		With low *FDMI*	With high *FDMI*	
	STV_within35 (least vulnerable)	67.12 (16.52)	57.54 (18.77)	**0.005**
	STV_beyond35 (most vulnerable)	63.83 (15.28)	31.90 (18.63)	**0.000**
		With low *FTMI*	With high *FTMI*	
	STV_within35 (least vulnerable)	71.37 (8.94)	54.25 (17.74)	**0.000**
	STV_beyond35 (most vulnerable)	66.98 (12.18)	33.90 (20.40)	**0.004**
Socio-economic vulnerability		With low *FDMI*	With high *FDMI*	
	SEV_1 (least vulnerable)	59.76 (15.56)	43.65 (19.10)	**0.000**
	SEV_4 (most vulnerable)	72.11 (9.84)	74.77 (9.97)	0.217
		With low *FTMI*	With high *FTMI*	
	SEV_1 (least vulnerable)	63.34 (14.44)	39.18 (17.24)	**0.000**
	SEV_4	70.42 (9.20)	72.07 (11.32)	0.460

(most vulnerable)

Note: If Levene's tests indicate that two samples have equality of variances ($p > 0.05$), t-tests are run assuming equal variances; otherwise, t-tests are run assuming unequal variances; The mean difference is significant at 0.05 level.