Analyzing income-based inequality in transit nodal accessibility

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ABSTRACT

Public transit is the main travel mode for residents in major urban areas to access different socioeconomic resources. Nodal accessibility can be used to measure the level of transit-based connectivity for residents from one neighborhood to socioeconomic resources in other neighborhoods. While many existing studies have measured the spatial inequality in nodal accessibility, few have comprehensively explored income-based inequality in nodal accessibility, especially between the richest and poorest of the population. This study examines the income-based inequality in nodal accessibility in Hong Kong using both the Gini coefficient and the 20:20 ratio. Our study shows that except Kowloon City, Sai Kung and Kwai Tsing, all districts suffer from some degree of inequality either among its middle-income residents or between its richest and poorest 20% residents. Besides, among all 18 districts, the poorest 20% living in Islands District not only have the lowest median monthly household income but also are most disadvantaged in terms of nodal accessibility compared to the richest 20% living in the same district. Overall, the results indicate that the Gini coefficient alone is inadequate in revealing the inequality between the richest and poorest of the population, while the 20:20 ratio can complement such inadequacy. Our results can inform policymakers to develop measures to alleviate income-based inequality in nodal accessibility.

1. Introduction

Public transit serves as a key travel mode for urban residents, especially for those without cars, to reach various socioeconomic resources. For many key urban centers that have extensive transit coverage (e.g., Hong Kong, New York, Tokyo and London) (Loo et al., 2010; Song et al., 2019), transit nodal accessibility, which traditionally measures how well connected a transit node is with other transit nodes in a transit network, can be used as a substitute for measuring the connectivity of

one neighborhood (and residents living in the neighborhood) to other neighborhoods (and the socioeconomic resources in those neighborhoods) based on different public transit modes (e.g., buses, trains, trams and ferries).

However, inequality, which has been revealed in the accessibility to a wide range of socioeconomic opportunities such as employment (Liu and Kwan, 2020), grocery (Farber et al., 2014), healthcare (Liu et al., 2021a) and recreation (Xu et al., 2017), also exists in transit nodal accessibility. While inequality in transit nodal accessibility can lead to

further inequality in accessing locations of socioeconomic opportunities (Lei et al., 2012; Pasha et al., 2020). Therefore, the alleviation of inequality in transit nodal accessibility should be a key policy concern for governments as it can help improve accessibility to a wide range of socioeconomic opportunities for the public, especially the transit-dependent. It is thus of great importance for policymakers to be informed of the inequality of nodal accessibility in order to formulate intervention measures aimed at alleviating such inequality holistically. Nevertheless, existing studies have mostly focused on revealing the spatial inequality of nodal accessibility (Jiao et al., 2014; Kim and Song, 2015; Kim and Song, 2018), while paying insufficient attention to the income-based inequality in nodal accessibility. Besides, past studies that measured income-based inequality have mostly adopted the traditional Gini coefficient to measure income-based inequality, which disproportionately focuses on the middle-income group while overlooking the inequality between the richest and poorest of the population (Cobham and Sumner, 2013; Guzman and Oviedo, 2018).

Based on the issues identified with the Gini coefficient as mentioned above, this study contributes to a more accurate measurement of inequality in nodal accessibility through the complementary metrics of the Gini coefficient and the 20:20 ratio. The 20:20 ratio can complement the Gini coefficient by measuring the inequality between the richest 20% and poorest 20% of the entire population and has been used in existing studies (Pascoal and Rocha, 2018; Roberts and Willits, 2015; Stensrud and Valberg, 2017). Besides, our research also seeks to provide policymakers with more appropriate and concrete policy recommendations that aim at alleviating the inequality gap based on the results yielded from the enhanced measurement.

This paper is organized as follows. Section 2 includes the research background. Section 3 describes the study area, data sources and methodology used in this study. Section 4 presents the results of this research and its analysis. The final section contains the discussion and conclusions of this study.

2. Research background

Public transit serves as a major travel mode for residents in many major cities around the world, such as Hong Kong, Singapore, Chicago, Tokyo and New York, to access various socioeconomic opportunities (Litman, 2015; Loo et al., 2010; Martinez et al., 2020; Song et al., 2019). Existing literature has extensively examined transit accessibility inequality. It can be divided into two categories. First, some studies focused on the inequality in accessibility to public transit infrastructures such as bus stops, transit stations, and ferry piers (Daniels and Mulley, 2013; van Soest et al., 2020). For example, van Soest et al. (2020) explored walking-based accessibility to public transit and showed that personal (e.g., gender, age and income), infrastructure-related (e.g., route spacing, travel mode type) and environmental (e.g., safety, walkability) factors all can affect inequality in accessibility to public transit. Second, some studies focused on the inequality in transit-based accessibility to various socioeconomic resources such as healthcare (Sharma and Patil, 2021; Tao et al., 2018), employment (Bocarejo et al., 2016; Liu et al., 2021b), grocery (Farber et al., 2014; Widener et al., 2017), recreation (Ermagun and Tilahun, 2020; Park et al., 2021) and education (Hernandez, 2018; Tiznado-Aitken et al., 2021). For example, Hernandez (2018) measured the transit-based accessibility to employment and education opportunities in Montevideo, Uruguay and found that people residing in more socially vulnerable neighborhoods have lower accessibility to those opportunities than people residing in less socially vulnerable neighborhoods.

For cities that have extensive transit routes and nodes such as those mentioned above, a unique type of transit accessibility called nodal accessibility can comprehensively reveal how connected residents are from one neighborhood to all kinds of socioeconomic opportunities in other neighborhoods around the city by public transit (Huang et al., 2020). Nodal accessibility has been mostly used to reveal spatial inequality in the connectivity between different transport nodes (Jiao et al., 2014; Kim and Song, 2015; Kim and Song, 2018), but it cannot directly reveal income-based inequality in transit connectivity.

Some recent studies (Kaplan et al., 2014; Welch and Mishra, 2013) have attempted to examine income-based inequality in nodal accessibility using the Gini coefficient, which is a traditional income-based inequality metric (De Maio, 2007; Qin et al., 2010). As one of the most popular income inequality metrics, the Gini coefficient, which is a single summary statistic within the range of 0 to 1, excels in representing the income distribution across the entire population with lower values indicating lower income inequality, and vice versa. However, the Gini coefficient is most sensitive to the middle-income groups but is incapable of differentiating different kinds of inequalities (Cobham and Sumner, 2013; De Maio, 2007; Guzman and Oviedo, 2018; Liu et al., 2021b). This means that the Gini coefficient is inadequate in revealing the inequality between those on the top and at the bottom (e.g., 20%) of the income spectrum. Besides its conventional application, the Gini coefficient has increasingly been repurposed for measuring inequalities in the provision of public transit (Delbosc and Currie, 2011), healthcare (Jian et al., 2015), and transport accessibility (Guzman et al., 2017; Jang et al., 2017). For example, Guzman et al. (2017) used the Gini coefficient to compare the car-based and transit-based accessibility to employment and educational opportunities in the Bogotá Metropolitan Region and found more equality in the transit-based accessibility to those opportunities. Jang et al. (2017) assessed the spatial equity of accessibility to the subway and bus in Seoul based on the Gini coefficient and found more equity in the distribution of subway accessibility than bus accessibility.

In the meantime, alternative inequality measures such as the 20:20 ratio have been used as a complementary metric for holistically examining income inequality. The 20:20 ratio is originally a distribution inequality metric and was obtained by dividing the average income of the richest 20% of the population by the average income of the poorest 20% of the population (Pascoal and Rocha, 2018). A higher 20:20 ratio indicates more inequality between the richest 20% and the poorest 20% of the population; while a lower 20:20 ratio indicates less inequality between the richest 20% and the poorest 20% (Sabbah et al., 2010). Unlike the Gini coefficient whose range is between 0 and 1, there is no fixed range for the 20:20 ratio. Compared to the Gini coefficient, the 20:20 ratio has the advantage of detecting the income inequality between the population on the top and at the bottom 20% of the income spectrum as well as being easy to calculate and communicate, which makes it a popular inequality metric with policymakers (Afonso et al., 2015). Nevertheless, the 20:20 ratio is not sensitive to the middle-income groups and thus also falls short of providing a holistic picture of income inequality across the entire income spectrum. Despite its original application in wealth inequality measurement, the 20:20 ratio has also been repurposed for examining other issues such as crime (Roberts and Willits, 2015; Thacher, 2004) and healthcare (Pickett et al., 2006; Stensrud and Valberg, 2017). Furthermore, the 20:20 ratio has also been recently used in tandem with the Gini coefficient, which helps yield a more comprehensive measurement of inequality. For instance, Stensrud and Valberg (2017) used both the Gini coefficient and the 20:20 ratio to highlight the considerable inequality in the genetic risk of getting cancer and found that the estimated inequality in genetic risk is higher than the inequality in income in the United States.

Despite the benefits of revealing a more holistic picture of inequality based on the complementary metrics of the Gini coefficient and the 20:20 ratio, many existing studies on the inequality of nodal accessibility have used only the Gini coefficient (Kaplan et al., 2014; Sharma et al., 2020; Welch and Mishra, 2013). Therefore, there is still a gap in applying the Gini coefficient and the 20:20 ratio together in measuring nodal accessibility inequality. Our study aims at filling this gap by adopting the integrated distribution inequality approach, which uses two complementary metrics including the Gini coefficient and the 20:20 ratio. This approach can more realistically measure income-based

inequality in nodal accessibility across the income spectrum. Specifically, we seek to apply the above-mentioned integrated inequality approach in Hong Kong based on open-source government data and address the question of which districts in Hong Kong have more serious income-based inequality in nodal accessibility.

3. Data and methodology

3.1. Study area

The study area for this research is Hong Kong, which is a special administrative region located on the southern coast of China. As of 2019, Hong Kong had a population of around 7.5 million but only 617,683 private cars (HKTD, 2019), which could serve only about 8.25% of the city's population and indicates heavy dependence on public transit for most of the city's residents. The extensive transit networks in Hong Kong consist of bus, tram, train and ferry routes and had daily transit patronage of 12.9 million passengers in 2019 (HKTD, 2019).

Geographically, Hong Kong can be divided into three large regions: Hong Kong Island, Kowloon and the New Territories. These three regions are divided into 18 administrative districts, which include Central and Western, Eastern, Southern, Wan Chai, Sham Shui Po, Kowloon City, Kwun Tong, Wong Tai Sin, Yau Tsim Mong, Islands, Kwai Tsing, North, Sai Kung, Sha Tin, Tai Po, Tsuen Wan, Tuen Mun and Yuen Long, as shown in Fig. 1.

Each one of the 18 districts has its own district council, which advises the Hong Kong Government on matters related to the general welfare of their constituents, and the provision and usage of public facilities and services such as public transit within the district. To illustrate the socioeconomic characteristics of Hong Kong, we constructed Fig. 2 to show the distribution of population density, transit density and median monthly household income in Hong Kong in 2016.

As shown in Fig. 2(a) and (b), the districts that have a large number of neighborhoods with a high density of population and transit services include Sham Shui Po, Kowloon City, Kwun Tong, Wong Tai Sin, Yau Tsim Mong, Central and Western, Eastern, Wan Chai, Besides. Fig. 2(a) and (b) also show that neighborhoods with high population density largely overlaps neighborhoods with high transit density, which is in line with the transit-oriented development model widely adopted in Hong Kong (Chow, 2014; He et al., 2021). Most residents living in

Central and Western, Eastern, Wan Chai and Southern appear to have higher income compared to residents of other districts, as shown in Fig. 2(c). Besides, the districts that appear to have the highest median monthly household income include Central and Western, Eastern, Wan Chai, Southern and Sai Kung; while the districts that appear to have the lowest median monthly household income include Sham Shui Po, Kwun Tong, North, Kwai Tsing and Wong Tai Sin. It is worth noting that three out of the five districts with the lowest median monthly household income also happen to have the highest population and transit service densities. Nevertheless, the level of inequality in transit node accessibility at the neighborhood level may appear very differently from that of the transit service density.

To better capture the distribution of wealth between the richest 20% and the poorest 20% of the population within each of the 18 districts in Hong Kong, we construct Table 1 to show the median monthly household income of each district in descending order.

As shown in Table 1, the poorest 20% in the districts of Islands, Sham Shui Po, North, Yau Tsim Mong and Kwun Tong have the lowest median monthly household income; while Southern, Wan Chai, Kowloon City, Central and Western and Islands have the highest levels of inequality in terms of median monthly household income between its richest 20% and poorest 20% residents. Based on this comparison, it can be seen that the poorest 20% in Islands District are doubly disadvantaged because, on one hand, they rank among the lowest in terms of median monthly household income in all 18 districts, and on the other hand, they have one of the largest income gaps when compared to the richest 20% living in the same district.

3.2. Data source

Our study uses the Large Street Block Group (LSBG) as the study unit. The LSBG is the smallest geographic area for which census data are available in Hong Kong (Monkkonen and Zhang, 2011). According to 2016 Hong Kong population by-census data, Hong Kong had 1,622 LSBGs. The data used in our research mainly come from two different sources. First, we obtain the latest 2016 population by-census socioeconomic information including LSBG-level population and median household monthly income from the Hong Kong Census and Statistics Department. Second, we collect the 2021 transit data, which includes the location of all bus/tram stops, ferry piers and train stations in the
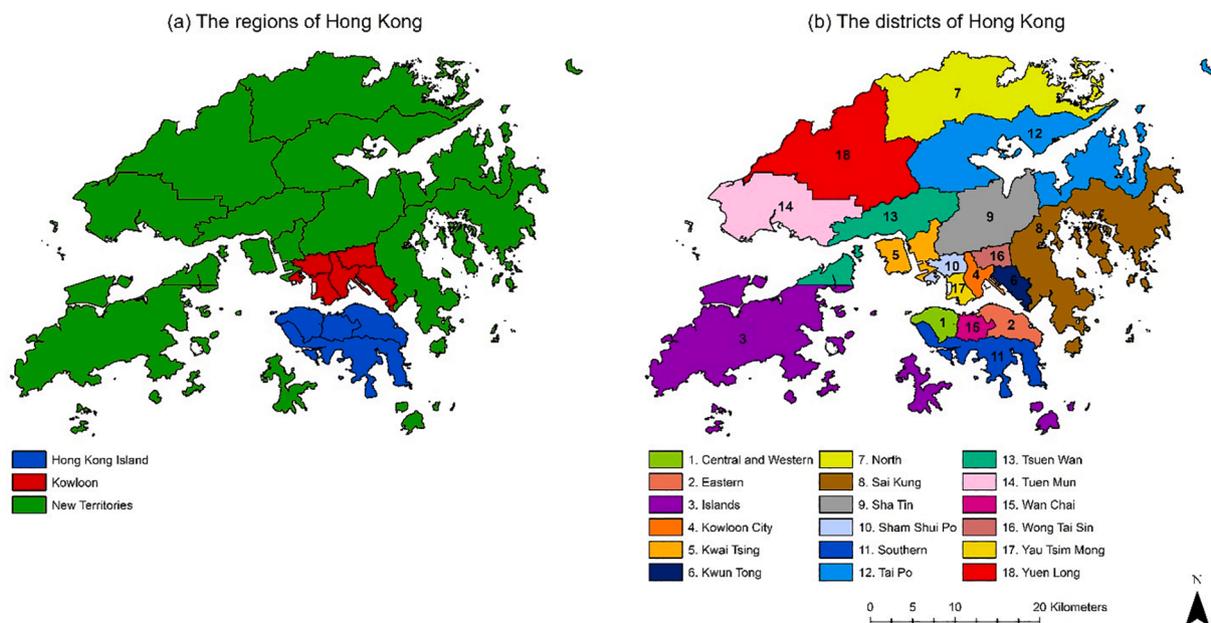

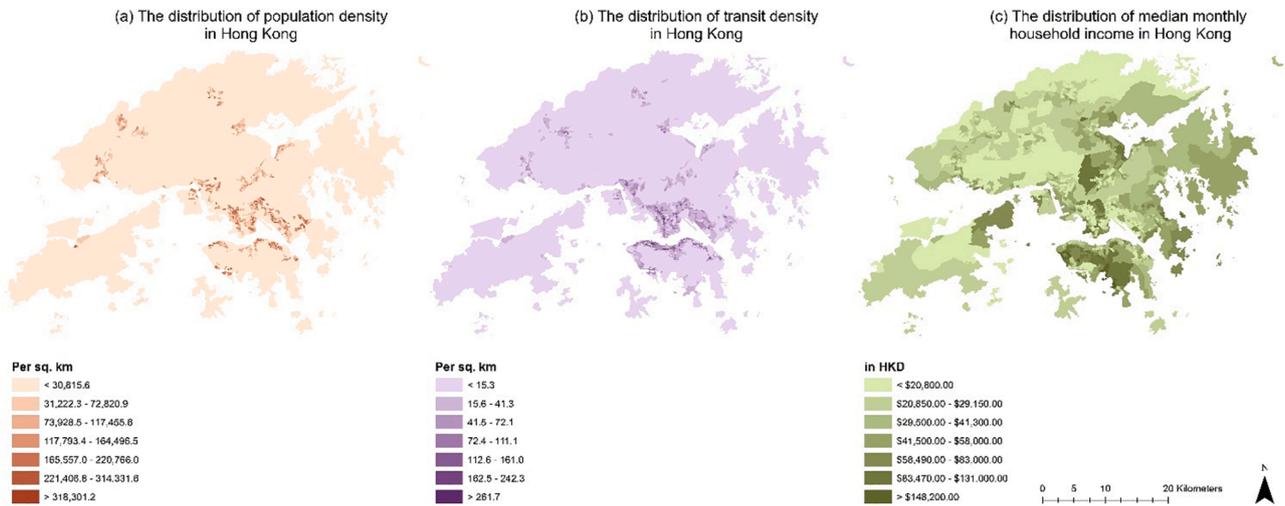**Fig. 1.** The regions and districts of Hong Kong.

Fig. 2. The distribution of (a) population density (b) transit density (c) median monthly household income in Hong Kong.

Table 1

Comparison of median monthly household income (in HKD) between the richest 20% and the poorest 20% of the population in the 18 districts of Hong Kong.

District	Richest 20%	Poorest 20%	Richest 20% : Poorest 20%
Wan Chai	99,000	18,800	5.266
Central and Western	105,000	21,250	4.941
Yuen Long	34,750	15,000	2.317
Kwun Tong	48,845	15,000	3.256
North	35,000	14,500	2.414
Wong Tai Sin	45,460	15,000	3.031
Eastern	68,600	18,660	3.676
Sha Tin	65,300	16,670	3.917
Tsuen Wan	51,570	16,340	3.156
Yau Tsim Mong	43,250	14,700	2.942
Sai Kung	56,410	21,250	2.655
Sham Shui Po	60,000	14,250	4.211
Kowloon City	82,000	16,420	4.994
Islands	57,080	13,380	4.266
Kwai Tsing	56,630	17,545	3.228
Tai Po	55,510	16,650	3.334
Tuen Mun	45,660	17,000	2.686
Southern	116,685	21,800	5.353

city, from the Hong Kong Transport Department (HKTD).

3.3. Methodology

In this section, we present the methods used for measuring nodal accessibility at the LSBG level as well as for calculating the nodal accessibility-based Gini coefficient (NA-Gini) and the 20:20 ratio at the district level. First of all, we measure nodal accessibility by considering each transit stop or station (i.e., bus stop, tram stop, train station and ferry pier) as a node, where a link connects transit node i and j according to the route networks. The nodal accessibility measure used in this study is based on Lee and Lee (1998), which integrated the inconvenience of transfer into the measure. Specifically, the public transit network can be regarded as a connection matrix C, the cell entries in matrix C represent the presence or absence of links between pairs of nodes. Based on it, we can further assign the value of 1 or 0 according to whether there is a direct connection between two different nodes in the network. Note that there may be several paths with different links between nodes i and j in the network since passengers have multiple choices in the public transit network (e.g., nodes i and j can be connected via bus and train, or bus and tram). For any path between nodes i and j, there may be $r - 1$ nodes p_i $(i = 1, 2, …, r - 1)$ with m transfers (i.e., a passenger has to transfer m

times along the path). It should be noted that passengers' travel behavior would be influenced by the inconvenience of transfer, which is regarded as the weighting scalar S. Namely, there is an additional factor S^m between a path connecting a pair of nodes i and j, which involves m transfers. Hence, the rth-order connectivity between node i and node j is estimated based on Eq. (1) as follows.

$$C_{ij}^{(r)} = \sum_{p_1, p_2, p_3, \cdots p_{r-1}} C_{ip_1} C_{p_1 p_2} C_{p_2 p_3} \cdots C_{jp_{r-1}} S^m \quad (1)$$

where $C_{ij}^{(r)}$ is the rth-order connectivity between nodes i and j. S $(0 < S < 1)$ is the scalar measure of the ineffectiveness of transfer and its value is set at 0.7 and the transit transfer distance tolerance threshold at 100-meter. The value for S and the criteria for transit transfer are set based on Huang et al. (2020), which calculated the nodal accessibility for the same study area.

Afterward, we proceed to calculate the nodal accessibility as a numeric score based on Eqs. (2) and (3).

$$T_{ij} = \sum_{r=1}^{r_{max}} D^r C_{ij}^{(r)} \quad (2)$$

where T_{ij} is the total connectivity between nodes i and j; D $(0 < D < 1)$ is the scalar measurement of the distance-decay effect and its value is set at 0.8. The value for D is also set based on Huang et al. (2020), which calculated the nodal accessibility for the same study area.

$$A_i = \sum_{j=1,2\cdots,n} T_{ij} \quad (3)$$

where A_i is the nodal accessibility of node i.

After calculating nodal accessibility, we then calculate the cumulative proportion of nodal accessibility and population at the LSBG-level. First, we calculate the nodal accessibility of each LSBG as a percentage of the summed nodal accessibility for all LSBGs within one district. Based on the nodal accessibility percentage at the LSBG-level, we calculate the cumulative proportion for each LSBG. Then, we calculate the population of each LSBG as a percentage of the total population for all LSBGs within one district. Based on the population percentage at the LSBG-level, we calculate the cumulative proportion for each LSBG. Afterward, we calculate the NA-Gini based on Equation (4):

$$G_u = 1 - \sum_{t=1}^{n_u} (A_{t+1} + A_t)(Q_{t+1} - Q_t) \quad (4)$$

where G_u is the nodal accessibility-based Gini coefficient (NA-Gini) of district u; n_u is the number of LSBG within district u; A_t is the cumulative proportion of nodal accessibility for n_u LSBGs; Q_t is the cumulative

proportion of the population for n_u LSBGs.

Finally, we calculate the 20:20 ratio based on Eq. (5):

$$E_u = \frac{\overline{A}_{u\_richest20\%}}{\overline{A}_{u\_poorest20\%}} \tag{5}$$

where E_u is the 20:20 ratio for district u; $\overline{A}_{u\_richest20\%}$ is the population-weighted average nodal accessibility for the richest 20% LSBGs of district u; $\overline{A}_{u\_poorest20\%}$ is the population-weighted average nodal accessibility for the poorest 20% LSBGs of district u.

4. Results and analysis

Based on Eqs. (1)–(3), we first calculate the nodal accessibility at the LSBG level and obtain the results shown in Fig. 3 based on the Jenks natural breaks classification scheme.

As shown in Fig. 3, the distribution of nodal accessibility appears to be very different from the transit density distribution in Fig. 2(b). Many LSBGs in districts that have high transit density (e.g., Sham Shui Po, Kwun Tong, Wong Tai Sin, Yau Tsim Mong, Eastern, Wan Chai) do not actually have high nodal accessibility, which indicates that high transit density does not necessarily translate directly into high nodal accessibility. Instead, some LSBGs in districts that have relatively low transit density (e.g., Islands, Sha Tin, Yuen Long) appear to have high nodal accessibility. This can be explained by the presence of new towns (e.g., Tung Chung, Tin Shui Wai) in New Territories districts such as Islands, Sha Tin and Yuen Long that are located on the periphery of the city. These new towns are built later than the established urban centers in districts located in Kowloon and Hong Kong Island such as Sham Shui Po, Yau Tsim Mong, Eastern and Wan Chai. The new towns were built based on the concept of transit-oriented development, which makes public transit more accessible by walking (Chow, 2014). Lu et al. (2018) have recently corroborated that residents who live in new towns have shorter walking times for public transit compared to residents who live in the established urban centers. Therefore, it is not unexpected to see districts (e.g., Islands, Sha Tin, Yuen Long) with relatively low transit density appear to have high nodal accessibility since these districts usually have a huge presence of new towns.

Meanwhile, neither Fig. 3 nor Fig. 2(b) reveal much about the intra-district inequality in nodal accessibility. In order to detect the intra-district inequality in nodal accessibility, we then proceed to calculate both the NA-Gini and the 20:20 ratio at the district level to compare the inequality in nodal accessibility across the entire population as well as between the richest and poorest of the population within each district respectively as shown in Fig. 4 and Table 2.

As shown in Fig. 4 and Table 2, the overall NA-Gini for Hong Kong is 0.47. By using the overall NA-Gini as the benchmark, we find that Wan Chai, Central and Western, Yuen Long, Kwun Tong, North, Wong Tai Sin, Eastern and Sha Tin have higher-than-benchmark NA-Gini, which means that the distribution of nodal accessibility across the population within each of these districts is less equal compared to that of the entire city. Meanwhile, Sai Kung, Sham Shui Po, Kowloon City, Islands, Kwai Tsing, Tai Po, Tuen Mun and Southern have lower-than-benchmark NA-Gini, which means that the distribution of nodal accessibility across the population within each of these districts is more equal compared to that of the entire city. Nevertheless, the range of the NA-Gini largely falls between 0.4 and 0.6, which indicates that the differences in nodal accessibility inequality across the entire population among the 18 districts are relatively small.

In comparison, the 20:20 ratio of nodal accessibility of the entire city is 0.75. Unlike the Gini coefficient, the 20:20 ratio does not have a fixed range. However, except for Islands, the 20:20 ratios of all other 17 districts fall within the range of 0 to 2. After considering Islands, the exact range of the 20:20 ratio varies substantially between 0.35 and 339.35. Nevertheless, this substantial range after considering Islands shows exactly the extreme inequality faced by some of the poorest residents living on Islands. Specifically, the values of the 20:20 ratio of Islands, Tsuen Wan, Yau Tsim Mong, Sham Shui Po, Tai Po, Tuen Mun and Southern are all higher than 1, which means that the richest 20% have better nodal accessibility than the poorest 20% in these districts. Among the districts whose 20:20 ratios are higher than 1, Islands District, with a 20:20 ratio of 339.35, has the worst inequality in nodal accessibility between the richest 20% and poorest 20% of its population; while the 20:20 ratios for the rest of the districts fall between 1.01 and 1.39. This may be explained by the fact that Islands District consists of one huge island called Lantau Island, which includes the Hong Kong International Airport and is well connected with the rest of the city by ferry, bus and train services, and many much smaller outlying islands (e. g., Cheung Chau, Lamma Island, Peng Chau), which are relatively remote and only connected with the rest of the city by a few ferry routes. Due to the attractive natural settings, less crowdedness and good transit coverage on Lantau Island, there are many high-end residential neighborhoods dwelled by high-income professionals who work in the central business districts such as Central, Sheung Wan and Tsim Sha Tsui. In comparison, most residents of the smaller outlying islands usually have been living there for many generations and tend to work in low-income occupations such as fishing, farming and service. As a result, the Islands district has such drastic income-based inequality in nodal accessibility between the richest 20% and poorest 20% of its population.

Furthermore, it should be particularly noted that none of the districts with a 20:20 ratio higher than 1 has higher-than-benchmark NA-Gini. This confirms that the NA-Gini is skewed towards the distribution inequality for the middle-income groups and the 20:20 ratio complements the NA-Gini by revealing the inequality between the richest and poorest of the population. In addition, the discrepancies between districts with high NA-Gini (i.e., Wan Chai, Central and Western, Yuen Long, Kwun Tong, North, Wong Tai Sin, Eastern and Sha Tin) and districts with high 20:20 ratios (e.g., Islands, Tsuen Wan, Yau Tsim Mong, Sham Shui Po, Tai Po, Tuen Mun and Southern) also indicate that the richest 20% and the middle-income population in the districts of Islands, Tsuen Wan, Yau Tsim Mong, Sham Shui Po, Tai Po, Tuen Mun and Southern enjoy higher nodal accessibility compared to the poorest 20% of the population in those districts.
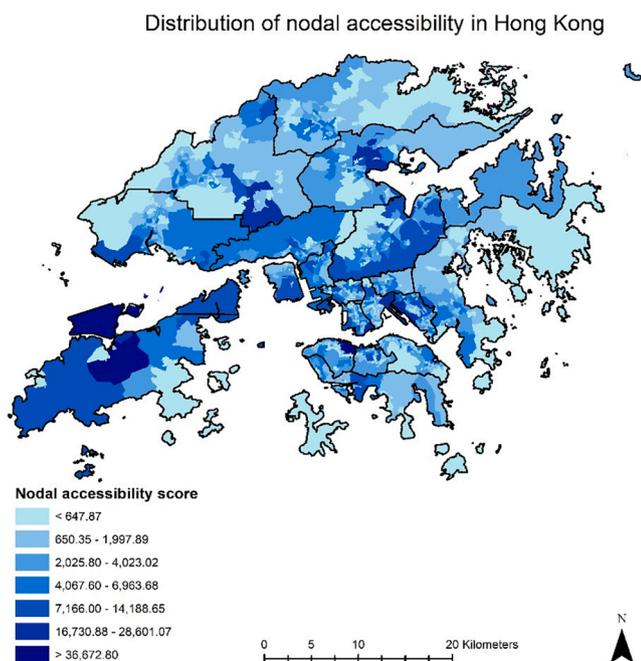

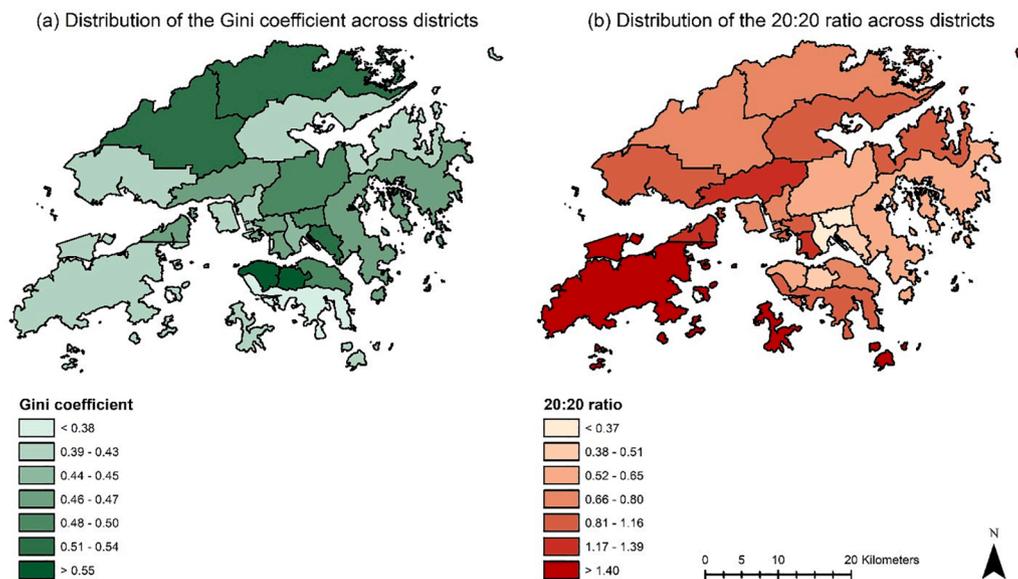Fig. 3. Distribution of nodal accessibility in Hong Kong.

(a) Distribution of the Gini coefficient across districts

(b) Distribution of the 20:20 ratio across districts

Gini coefficient
- < 0.38
- 0.39 - 0.43
- 0.44 - 0.45
- 0.46 - 0.47
- 0.48 - 0.50
- 0.51 - 0.54
- > 0.55

20:20 ratio
- < 0.37
- 0.38 - 0.51
- 0.52 - 0.65
- 0.66 - 0.80
- 0.81 - 1.16
- 1.17 - 1.39
- > 1.40

0   5   10   20 Kilometers

Fig. 4. Distribution of (a) the Gini coefficient, and (b) the 20:20 ratio across districts.

Table 2
The NA-Gini and the 20:20 Ratio by district.

District	NA-Gini	20:20 Ratio
Wan Chai	0.58	0.45
Central and Western	0.58	0.54
Yuen Long	0.54	0.73
Kwun Tong	0.53	0.51
North	0.52	0.80
Wong Tai Sin	0.50	0.35
Eastern	0.49	0.80
Sha Tin	0.48	0.57
Tsuen Wan	0.47	1.39
Yau Tsim Mong	0.47	1.34
Sai Kung	0.46	0.65
Sham Shui Po	0.46	1.16
Kowloon City	0.45	0.37
Islands	0.43	339.35
Kwai Tsing	0.42	0.71
Tai Po	0.42	1.09
Tuen Mun	0.41	1.06
Southern	0.38	1.01
Total	**0.47**	**0.75**

5. Discussion and conclusion

Our study measures LSBG-level nodal accessibility and compares the income-based inequality in nodal accessibility across the 18 districts in Hong Kong. We find that although inter-district NA-Gini differences are relatively small, inter-district 20:20 ratios have a wide range, which indicates that the inequality in nodal accessibility between the richest 20% and poorest 20% of the population varies significantly across districts.

Based on the NA-Gini, we find that 8 districts, which include Wan Chai, Central and Western, Yuen Long, Kwun Tong, North, Wong Tai Sin, Eastern and Sha Tin, have higher-than-benchmark NA-Gini. This suggests that inequality in nodal accessibility across the population of all income levels in these districts is more serious than in the entire city. Among these districts, Wan Chai and Central and Western have the highest NA-Gini and are around 23.40% higher than that of the entire Hong Kong, which means that both districts are 23.49% more unequal than the entire city. However, it should be noted that the NA-Gini differences between these 8 districts and the entire city are not substantial as the values of the NA-Gini of these districts fall between 0.4 and 0.6.

Based on the 20:20 ratio, we find that 7 districts, which include

Islands, Tsuen Wan, Yau Tsim Mong, Sham Shui Po, Tai Po, Tuen Mun and Southern, have 20:20 ratios higher than 1, which means that, in these districts, the richest 20% of the population have higher nodal accessibility than the poorest 20% of the population. This should be alarming for the district councilors of these districts because disadvantages in nodal accessibility for the poorest 20% can lead to disadvantages in accessing a wide range of socioeconomic resources such as employment, education, healthcare and recreation, which in turn result in further deterioration in the socioeconomic status of the poorest 20% of the population and lead to a downward spiral. Moreover, we find that the Islands District has a particularly high 20:20 ratio of 339.35, which may be attributed to the inequality between the high-income residents working in the central business districts but living on Lantau Island, which has lots of greenery and is well connected to the rest of the city by frequent ferry, train and bus services, and the low-income residents working in the farming, fishing and service industries and living for generations on the outlying islands, which are only connected to the rest of the city by a few ferry routes. It is also worth noting that the districts with wider gaps between the richest 20% and the poorest 20% (i.e., the districts whose 20:20 ratios are higher than 1) usually have relatively lower NA-Gini, which means that the middle-income residents in these districts have good nodal accessibility.

When comparing the districts with higher-than-benchmark NA-Gini and the districts whose 20:20 ratios are higher than 1, the results reveal a complex landscape of inequality in transit nodal accessibility based on the two different metrics. While some districts (e.g., Tsuen Wan, Yau Tsim Mong, Sham Shui Po) have a relatively equal distribution of nodal accessibility among all its residents, the poorest 20% residents of these districts can be faring much worse compared to the richest 20% residents in the same districts. In comparison, some other districts (e.g., Yuen Long, Kwun Tong, North) may have smaller gaps between its poorest 20% and richest 20% residents, the inequality among all their residents across income levels can be high. Nevertheless, the Hong Kong Government should pay more attention to the poorest 20% of the residents living in the 7 districts of Islands, Tsuen Wan, Yau Tsim Mong, Sham Shui Po, Tai Po, Tuen Mun and Southern because the poorest 20% of residents in these districts not only reside at the bottom of the economic ladder but also have much lower nodal accessibility than their richest 20% counterparts, which in turn lower the likelihood for the poorest 20% in accessing opportunities (e.g., better employment) that can improve their economic outcomes.

Therefore, the Hong Kong Government should consider proposing

policies that target specifically the poorest 20% of neighborhoods in those 7 districts by adding more transit routes linking the poorest 20% of neighborhoods to major transit nodes in other parts of the city. In Hong Kong, major Mass Transit Railway (MTR) transit nodes such as Admiralty and Hung Hom can provide passengers with multiple direct transit options to many destinations around the city. The ongoing construction and recent proposal of MTR route extensions (e.g., Tuen Mun South Extension; Sha Tin to Central Link) serve as good examples of transit coverage expansions that seek to directly connect more residents with major transit nodes. Although the MTR Tuen Ma Line connects some residents in Tuen Mun to major downtown transit nodes like Hung Hom, the current terminus of the MTR Tuen Ma Line does not cover residents living Tuen Mun South, which forces residents there to take a bus or light rail train first in order to access the MTR Tuen Ma Line. This may explain our findings regarding the nodal accessibility inequality faced by the poorest 20% of residents in Tuen Mun. The construction of the Tuen Mun South Extension can help alleviate the inequality by providing much more residents living in Tuen Mun South with direct access to the MTR Tuen Ma Line. Among all the districts, the poorest 20% of neighborhoods within the Islands District should be given extra attention as they appear to fare much worse compared to the richest 20% living in the same district. Although the geographic reality (i.e., the spiraling distribution of and huge water distance among many outlying islands except Lantau Island) of the Islands District renders massive transit infrastructure infeasible, the government should at least consider adding more direct ferry services to ferry piers (e.g., Kowloon Public Pier, Central Pier), which are close to mass transit hubs, to some of the most disadvantaged outlying islands with a relatively large population (e.g., Lamma Island, Peng Chau and Cheung Chau).

Although we only consider spatial constraints in this study, other studies have shown that transit accessibility can be affected by temporal and economic constraints such as transit service frequency (Lee and Miller, 2018), operation hours (Wei et al., 2017) and fare costs (Verbich and El-Geneidy, 2017). Therefore, the Hong Kong Government should also consider maintaining the transit frequency and operating hours in the disadvantaged neighborhoods at a level at least on par with the richer neighborhoods in the same district; while formulating concessionary fare schemes aimed at alleviating the financial burden for lower-income residents. Given the fact that the existing government-subsidized transit fare concession scheme in Hong Kong only targets the elderly and disabled people, the government should consider expanding concessionary fare to also cover lower-income residents.

We acknowledge that there are some limitations in this research due to data availability. On the one hand, we do not integrate the service capacity and temporal constraints (e.g., operation hours and frequency) into our measurement of accessibility. On the other hand, the impact of transit fares has also not been considered in our study. The integration of service capacity and the temporal and economic dimensions can serve as future research directions in measuring access to public transit.

6. Data availability statement

All data used in this study are public data available on the web.

CRediT authorship contribution statement

Dong Liu: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Mei-Po Kwan:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Jianwei Huang:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Zihan Kan:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Yimeng Song:** Writing – original draft, Writing – review & editing. **Xuefeng Li:** Writing – original draft, Writing – review & editing.

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