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Spatial equity in accessing secondary education: Evidence from a gravity-based model

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Key Messages

- Access to secondary schools, especially prestigious key schools, is highly unequitable in urban China.
- Accessibility of key secondary schools is significantly associated with socio-economic characteristics of a neighbourhood.
- Due to both socialist and market mechanisms, neighbourhoods with higher socio-economic status have greater access to (better) secondary education.

Whereas education inequality has attracted wide scholarly attention, there has been little attention paid to the spatial patterns of schools or, more specifically, the spatial equity of secondary schools. This study investigates the spatial patterns of secondary schools (regular vs. key) in Guangzhou, China and disparities in school accessibility among different social groups at the neighbourhood level. We use a two-step floating catchment area method to measure school accessibility. Our results demonstrate strong spatial disparities in secondary school accessibility in Guangzhou and further underscore significant associations between the access to secondary schools, especially key schools, and neighbourhood characteristics. This study helps to document salient spatial inequity in China's current education system and suggests that efforts should be made to reduce the country's spatial inequity in secondary education.

Keywords: education inequity, school accessibility, secondary school, spatial equity, two-step floating catchment area method

L'équité spatiale en matière d'accès à l'enseignement secondaire : preuves obtenues d'un modèle gravitaire

Considérant que l'inégalité en matière d'éducation a attiré l'attention d'un grand nombre d'universitaires, peu d'entre eux se sont toutefois intéressés aux modèles spatiaux des écoles ou, plus précisément, à l'équité spatiale des écoles secondaires. Cette étude examine les modèles spatiaux des écoles secondaires (régulières versus spécialisée) à Guangzhou, en Chine, et les disparités dans le domaine de l'accessibilité aux écoles parmi différents groupes sociaux au niveau du quartier. Nous utilisons une méthode de zone de recrutement

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variable en deux étapes pour mesurer l'accessibilité aux écoles. Nos résultats démontrent l'existence de fortes disparités spatiales dans l'accessibilité aux écoles secondaires à Guangzhou et ils soulignent de plus des associations significatives entre l'accès aux écoles secondaires, particulièrement les écoles spécialisées, et les caractéristiques du quartier. Cette étude documente l'inégalité spatiale importante dans le système d'éducation chinois actuel et suggère qu'il faudrait faire des efforts pour diminuer l'inégalité spatiale du pays dans le domaine de l'enseignement secondaire.

Mots clés : inégalité en matière d'éducation, accessibilité aux écoles, enseignement secondaire, équité spatiale, méthode de zone de recrutement variable en deux étapes

Introduction

Geographers and city planners have paid close attention to the issues concerning the spatial equity of public facilities, that is, how the geographic locations of public services are associated with the distribution of different social groups (Alonso 1971; Bennett 1983; Birmingham & Wood Architects and Planners et al. 1993; Truelove 1993). There has been abundant research in the geography literature on access to various types of services and facilities, such as green spaces, public services, and health centres (Meter et al. 2011; Neutens et al. 2012; Wolch et al. 2014; Fransen et al. 2015; Hu 2015; Xu et al. 2015). However, there have been relatively few studies on the spatial patterns of schools. Moreover, whereas education inequality has attracted wide scholarly attention (Turner 1960; Talen 2001; Lipman 2004; Roscigno et al. 2006), little effort has been made to understand its spatial dimension, namely, the spatial equity of school distribution. The importance of education in social, political, and economic life is widely acknowledged, as it is among the most significant assets influencing one's career, and one of the most meaningful ways to promote social equity and justice, despite the fact that many societies fall short in meeting social equity and justice goals (Rong and Shi 2001; Roscigno et al. 2006; Dunne 2007).

Given the importance of schools as a fundamental facility for formal education, this study aims to bridge the literatures on accessibility and education inequality by examining the spatial pattern of secondary schools and its association with the socio-economic characteristics of urban neighbourhoods in the metropolitan city of Guangzhou, China. Special attention is paid to junior secondary schools (Grades 7–9) because junior secondary education is the last stage of compulsory education before non-compulsory senior secondary education (Grades 10–12) in China. Therefore, the quality of education received at this stage is critical for a student's future education and career (Li 2003; Adams and Hannum 2005; Fu and Ren 2010; Wang and Gu 2012).

China has made impressive achievements in school enrollment over the past three decades, including the expansion of nine-year compulsory education since 1986 (Yeoh and Chu 2014). Based on the 2010 population census, the enrollment rate for elementary schools (Grades 1–6) reached 99%, while that for secondary schools (Grades 7–12) was 90%. Nonetheless, there have been persistent disparities in the quality of education among different schools due to a stratified school system in urban China. Specifically, schools are divided into key schools and regular schools, which are entitled to different educational resources. In other words, educational expansion has not led to equitable access to education opportunities. Rather, a concentration of good teachers, equipment, funds, and other resources in key schools perpetuates education inequality among different social groups so that who gets access to better basic education tends to rely on one's family background. Because of the scarcity of resources, housing within the catchment of key schools becomes a hot spot for parents who compete for educational resources. As a result, education inequality in China may find its manifestation in the spatial pattern of schools in relation to socio-economic characteristics of surrounding neighbourhoods.

This paper aims to present the spatial dimension of education inequality in China by examining secondary school accessibility, with a special focus on key schools. Specifically, we address the following questions: First, what are the spatial patterns of secondary schools (regular vs. key) in Guangzhou? Are they fairly distributed geographically? Second, what is the relationship between school accessibility and socio-economic characteristics of surrounding neighbourhoods? Are particular groups at a disadvantage with regard to regular or key school accessibility? We next review the literature on spatial accessibility of public facilities, especially schools.

Literature review

Spatial accessibility to public facilities has been an important topic in the geography literature. Existing studies have focused on access to green space, such as parks (Talen 1997; Lindsey et al. 2001; Oh and Jeong 2007), playgrounds (Talen and Anselin 1998; Hewko et al. 2002; Smoyer-Tomic et al. 2004), and health care facilities (Knox 1978; Maas et al. 2006; Apparicio et al. 2008). Only a handful of studies focus on school accessibility, including access to daycare and to elementary and secondary schools (Pinch 1987; Pacione 1989; Truelove 1993; Talen 2001; Dunne 2007; Fransen et al 2015). This may be partly due to limited geographic data on schools. Furthermore, public provision of schools and related amenities (e.g., school buses) makes the issue of social barriers to school access less significant in some countries and regions (Talen 2001; Gimpel and Schuknecht 2003). Yet, the highly stratified secondary school system in urban China (which we will elaborate on in the subsequent section) makes the topic of spatial equity relevant to the country's education system.

Previous studies on accessibility have revealed different patterns of socio-economic disparities in access to public facilities (Talen 1997; Nicholls 2001; Barbosa et al. 2007; Wolch et al. 2014). For instance, while a number of studies show that socio-economically disadvantaged and racial/ethnic minority groups tend to have poorer access to green space in most cities in the United States (Dai 2011; Wolch et al. 2014), some found the opposite pattern in the United Kingdom—that is, more deprived groups and older people enjoy the greatest access to green space (Barbosa et al. 2007). Relatively equal access to urban green space among different social groups was found in China (Fan et al. 2017).

Patterns of school accessibility (including daycare facilities) vary as well in different research contexts and across various types of educational facilities. Truelove (1993) found no strong correlations between the distribution of daycare services and social groups within a 2 km radius in Toronto, suggesting equitable access to this service. Talen (2001) showed that there was substantial inequity in the access to elementary schools across regions in West Virginia, yet the relationship between neighbourhoods' socio-economic attributes and school access was inconclusive. Williams and Wang's (2014) research revealed that accessibility to high school in urban areas in Louisiana was unequal: African American students had poorer accessibility and thus poorer academic performance. This may be due to white flight in urban areas, which drives the suburbanization of good-quality private schools. Moreno-Monroya et al. (2018) revealed that existing inequalities in the São Paulo Metropolitan Region in Brazil may be amplified by the varying accessibility of secondary schools, and that the variation co-existed across income groups and geographical space. For example, low-income students often have low school accessibility because they live in areas with poor transportation facilities. In Xiantao, China, Tang et al. (2017) found regional differences in primary school accessibility: township centres have better access to primary schools compared to rural areas.

The findings from different contexts have been inconsistent regarding the spatial and socio-economic divide in school accessibility. Furthermore, these results are not readily transferrable to secondary education in the Chinese context. The literature seems to suggest that as educational resources (e.g., high schools) become scarce and accessing such resources becomes more competitive, population groups with lower socio-economic status are more likely to be marginalized in accessing high-quality resources, especially if effective public policies are not in place to elevate the spatial equity of public facilities. Also, regional divide (urban vs. suburban/rural) should be taken into account in assessing the spatial equity of school access.

One should also note that the inconsistent findings discussed above may be partly due to how accessibility is defined and measured differently. Below we discuss how we define and measure accessibility and spatial equity in this research.

Defining accessibility

While accessibility involves both spatial and social dimensions—e.g., social and cultural barriers)

(Lindsey et al. 2001; Coombes et al. 2010)—our analysis, following the most commonly adopted definition in the geography literature (Talen and Anselin 1998), confines the definition of accessibility to spatial access, that is, the availability of facilities within a given area in terms of ease of access and amount of services. Methods to assess spatial accessibility can be divided into two general approaches—the minimum travel cost approach and the coverage approach (Talen and Anselin 1998). The travel cost approach emphasizes the total impediments to reaching a facility. Different methods have been applied to gauge minimum travel costs, including minimum distance, buffer areas, cost weight distance, and network analysis (Nicholls 2001; Li and Liu 2009). The coverage approach considers the amount of service available within a defined area. This amount can be denoted by the total number of facilities within defined coverage or the average number of facilities per capita within an area (Wolch et al. 2014; Fan et al. 2017). While both approaches are easy to interpret, they may nevertheless provide a biased understanding of accessibility of schools as they only focus on one aspect of accessibility. School accessibility should be viewed as a function of both distance (how far a school is from one's residence) and capacity (how many services a school can provide within the catchment). In this regard, we employ a more holistic method, the two-step floating catchment area method (2SFCA), to take into account both the distance and the capacity of schools in measuring accessibility.

2SFCA is a gravity-based model for analyzing the access to public amenities. The method, first developed by Luo (2004) to evaluate access to physicians, is widely used in spatial accessibility studies and takes into account both the supply and demand sides of public amenities including primary care physicians (Luo and Qi 2009), residential care resources (Cheng et al. 2012), and parks (Dai 2011; Gu et al. 2017). Later, this method was further improved to analyze other research issues. Specifically, a commuter-based two-step floating catchment area method was developed to measure the spatial accessibility of daycare centres in East Flanders, Belgium (Fransen et al. 2015). An enhanced two-step floating catchment area (E2SFCA) method was used to measure spatial equity and the access to maternal health services in Indian Sundarbans (Vadrevu and Kanjilal 2016). A grid system was recently added to measure accessibility of urban green space in Macao, China (Ye et al. 2018). These 2SFCA-based methods use various threshold distances, different supply/demand catchment areas, and distinct decay equations specific to the research context. These methodological details will be addressed in the methods section.

Defining equity

The concept of equity corresponds to the fairness or justice of the distribution of resources (Truelove 1993; Hillsdon et al. 2006). Equity does not mean equal distribution of public goods for all groups; rather, it emphasizes the provision of goods or services in proportion to the needs or demand (Lucy 1981; Bennett 1983). In this regard, equality may be viewed as a subset of equity. According to Truelove (1993), the concept of equity in geography entails both "horizontal" and "vertical" dimensions. While horizontal equity refers to equitable distribution of public goods/services across regions or places, vertical equity means equitable distribution of resources among different socio-economic groups. Spatial equity of access to secondary schools entails both dimensions since it concerns the spatial access to schools in relation to socio-economic attributes of neighbourhoods. Equity in spatial access to secondary education means all people who are eligible for educational resources should have equal access to the education system, regardless of the locations of their residence and characteristics of their neighbourhood.

Stratified school system and education inequality in urban China

In China, despite the growing number of private schools and especially private senior secondary schools, public schools financed by local governments still dominate the secondary education system (Hannum and Wang 2006). While one may expect an education system dominated by public schools to provide equal education opportunities to school-aged population, the stratified senior secondary school system and an implicit tracking system of junior secondary schools in China have produced persistent inequality in education, as elaborated below.

The senior secondary school system in China is characterized by a tracking system whereby students are allocated, through an open competition, to different tracks—key schools and regular schools—which differ significantly in the qualifications of the teachers, financial resources, and educational facilities (Cao 2008; Wang and Gu 2012). Those who enroll in a key senior secondary school have a much better chance to get admitted to prestigious universities and hence will have significantly better career prospects in the future. The key school system was established by the Chinese Education Administration in 1962 in order to meet personnel demands with inadequate financial support (Zhang and Kanbur 2005; Hannum and Wang 2006). Since 2006, the establishment of key schools has been legally prohibited by the Chinese Compulsory Education Law in order to provide equal education opportunities. Yet key schools continue to exist under names such as experimental school, exemplary school, demonstrative school, or other names.

Most junior secondary schools are independent of senior secondary schools. However, large secondary schools, especially key schools, have both junior and senior sections. As part of China's compulsory education system, the junior secondary school system aims to offer equal education opportunities for all students, and adopts a nearest-school enrollment principle (*jiujin ruxue*) for student recruitment as officially mandated by the Chinese Ministry of Education in 2014. However, an implicit tracking system exists in junior secondary schools (Cao 2008; Hannum et al. 2010): students who attend key schools at the junior secondary stage tend to perform better in the entrance examination for senior high school due to better educational resources in key schools (Wang and Gu 2012). These students may be given priority to continue their senior secondary education in the same school with both junior and senior sections (Fang 2005; Wang and Gu 2012).

The implicit tracking system in junior secondary education distinguishes junior sections in key secondary schools from regular junior secondary schools and junior sections in regular secondary schools; this distinction further makes key junior schools/sections a scarce resource. Because the catchment areas of junior secondary schools are defined according to the nearest-school enrollment principle, those students who live close to key schools are more likely to study in those privileged schools. As a result, housing in the catchment area where a key secondary school is located becomes essential for students to access valuable educational resources. Studies (Shi and Wang 2014; Yi and Huang 2014) reveal that housing prices near key schools have skyrocketed in recent decades in metropolitan cities such as Beijing, Shanghai, and Guangzhou, and that adjacency to key schools ranks as the second pivotal factor influencing residential housing prices in Shanghai. In Guangzhou, the housing prices near key school districts were found to be two to three times those in other areas in the period 2015–2016. Consequently, enrollment in a regular or a key secondary school is affected directly by a family's housing choice, and indirectly by the socio-economic status of a family (Wu 2013).

The effect of family background on educational opportunities has been an important topic of social inequality in China. It is found that, in general, students whose parents are government employees, professionals, or entrepreneurs are much more likely to attend key schools and gain a better education than those whose parents are manual workers, farmers, or unemployed (Xie and Wang 2006; Li 2010). Migrant workers and the urban poor are also less likely to be able to offer good education opportunities to their children (Hannum 2005). Against the backdrop of the great market transformation in China over the past three decades, scholars disagree about the temporal changes of educational inequality in China. While some argue that educational inequality among different social groups has decreased in recent years due to the introduction of the compulsory education system (Jordan et al. 2014), others have shown that there is a persistent disparity in education among children from different family backgrounds (Saccone 2008). Moreover, education inequality in public elementary schools has been reduced due to the expansion of the compulsory education system, but it has increased in secondary schools (Li 2003; Li 2010; Jordan et al. 2014).

What is missing in existing studies is the spatial equity of access to education, or more specifically, how educational inequality is manifested in spatial access to schools. Whereas junior secondary schools as public goods are in principle relevant to the intellectual enquiry about social inequality, families with high socio-economic status are more likely to afford housing close to key schools and thus offer better educational opportunities for their children. The spatial dimension of educational inequality warrants the attention of scholars who are keen to understand China's urban transformation.

In the 1990s, China experienced an unprecedented process of urbanization and suburbanization soon after the country's economic reforms. Up until the early 2000s, the suburbanization of Chinese cities has been largely driven by residential and industrial relocation (Zhou and Ma 2000). After 2000, a new wave of suburbanization further escalated urban sprawl. This process was led by the government-sponsored new town development through administrative annexation and the expansion of mass transit systems (Zhang and Wu 2006; Shen and Wu 2017). As a result, Chinese metropolitan cities can be broadly divided into three areas based on different stages of urbanization: the inner city, or city centre, which has the highest density and a concentration of urban population; the inner suburb, which has mixed land use and is well connected with the city centre by public transit; and the outer suburb, which mainly consists of rural land use but also includes large-scale residential development and government-planned development such as satellite cities and industrial parks.

The fast pace of urbanization and suburbanization has greatly affected the spatial patterns of secondary schools. The large-scale rural-to-urban migration has resulted in an oversupply of schools in rural areas and an undersupply in urban areas (Sicular et al. 2007; Cao 2008). As a result, local governments consolidate schools in rural areas and expand schools in urban areas (Cao 2008). In the meantime, suburbanization affects both the number and quality of schools across different places in urban areas. As a large number of residents move from the inner city to the suburbs, the demand for schooling in suburban areas increases (Lu et al. 2017). According to the Chinese Code of Urban Residential Areas Planning & Design (GB 50180-93), new residential development projects are required to provide schools at a scale that corresponds to the number of residents in that community. However, the supply of schools in the suburbs, especially good-quality schools, is far from meeting demand. As a result, many students in the suburbs have to commute a long distance in order to pursue a better education opportunity, which enlarges the spatial mismatch between residence and school (Lu et al. 2017).

Based on the discussion above, we expect that spatial access to secondary schools is affected by both the socio-economic status and location (inner city, inner suburb, or outer suburb) of a neighbourhood. Three propositions are outlined below:

(1) Compared with regular schools, key schools are more skewed in their geographic distribution. Disparities in the spatial access to key schools among neighbourhoods are more salient than disparities in the spatial access to regular schools.
(2) Key school accessibility is highly correlated with the socio-economic attributes of a neighbourhood. That is, neighbourhoods with higher socio-economic status have better access to key schools.
(3) School accessibility is differentiated among different levels of urbanization: inner city, inner suburb, and outer suburb. Inner cities are expected to have the best access to key schools. Access to regular schools is expected to be more equitably distributed across these three areas.

Study area, data, and method

Study area

This study is situated in Guangzhou, the third-largest city in China after Beijing and Shanghai in terms of its economy. Located on the country's southeast coast, Guangzhou is the capital city of Guangdong Province and the core city of the Pearl River Delta mega-region (Figures 1a and 1b). Since the market reforms of the late 1980s, Guangzhou has experienced rapid economic development—the average annual economic growth rate reached about 14%, compared to 9% for the nation as a whole in the same period. Its proportion of urban population reached 86% in 2015, comparable to the urbanization levels of some developed countries such as the United States, France, and Australia.

Guangzhou has a total land area of 7,434 km^2, and consists of 12 administrative districts, 166 towns, and 2,643 neighbourhoods (Figure 1c). Based on its amount of built-up area and population density, the city can be divided into three areas: inner city, inner suburb, and outer suburb. The districts of Yuexiu, Liwan, Haizhu, and Tianhe are commonly recognized as the inner city area, which contains about

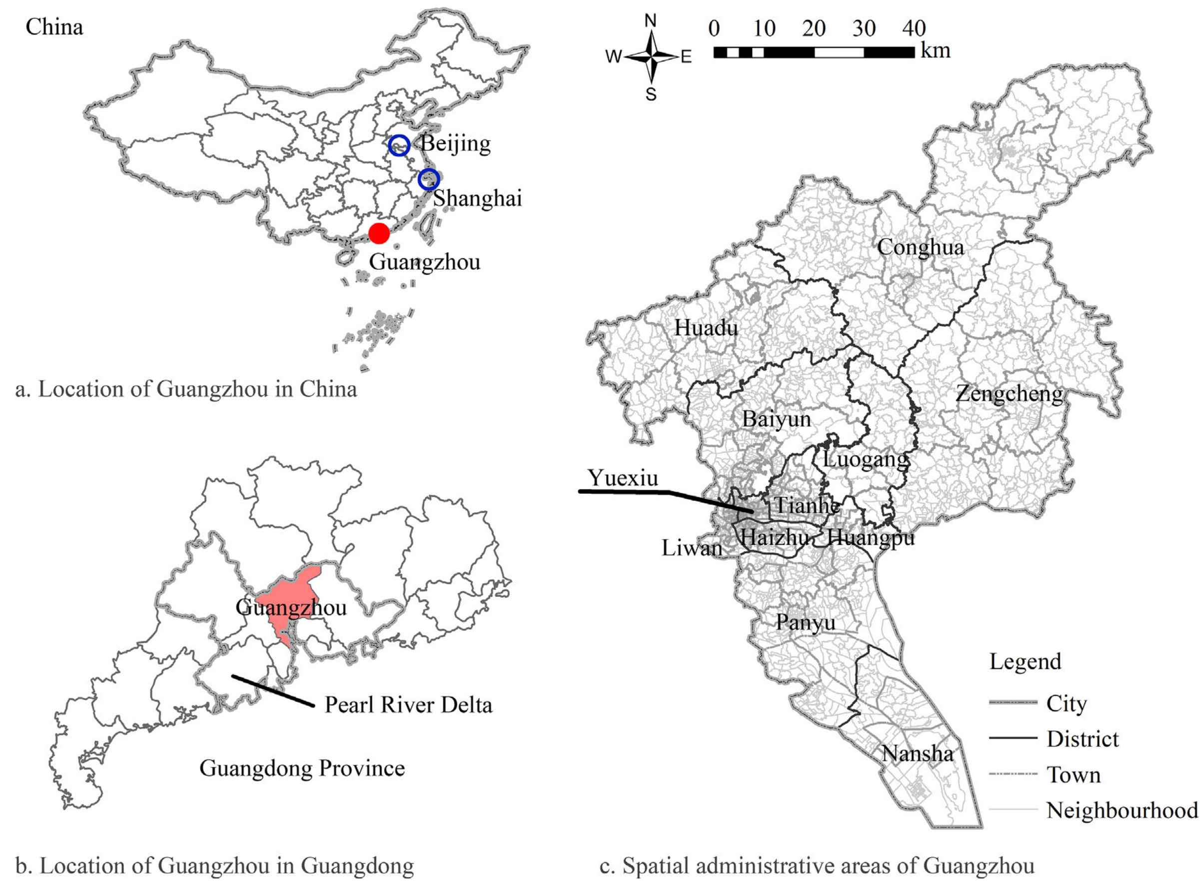

Figure 1
The study area.

40% of the city's population. For historical reasons, key schools and better education amenities are concentrated in this area. Baiyun, Huangpu, Panyu, and Luogang are the inner suburb districts, which contain most of the city's industrial sectors and a sizable floating population. The inner suburb districts in general have poorer education facilities than the inner city area, because many of the secondary schools have been built in recent years. Panyu and Huangpu districts, however, may have better access to schools because real estate developers were required to provide good-quality education facilities along with the large-scale development of commodity housing projects. The districts of Huadu, Nansha, Zengcheng, and Conghua are in the outer suburb, which has a large proportion of the rural population, but these districts are not considered rural areas due to the popular presence of satellite towns and industrial development zones. Some key schools are also located in the outer suburb because these districts used to be independent counties of the neighbouring Guangzhou city.

Education expenditure in Guangzhou increased 13 times, from 2 billion CNY (Chinese Yuan), or approximately USD $0.4 billion, in the late 1990s, to 29 billion CNY, or approximately USD $4.6 billion, in 2015. As a result, education facilities increased rapidly both in quantity and quality. The total number of secondary schools increased from 388 in 2000 to 510 in 2015, and the average ratio of students to teachers dropped from 18 in 2000 to 12 in 2015. Furthermore, the city government is considering extending compulsory education from 9 years to 12 years in the near future, with the aim of enhancing the coverage of secondary schools and equity of access to the schools (Guangzhou Municipal Government 2011). Whether these efforts could result in more equitably distributed secondary schools across urban space and social groups remains to be studied.

Data

We acquired data for secondary schools in 2016 from the Department of Education of Guangdong Province. This dataset includes a complete list of secondary schools in Guangzhou with the school's name, address, type (provincial key school, municipal key school, or regular school), and enrollment size. Each school address is then translated into geographic coordinates for analysis in ArcGIS.

The most recently available neighbourhood-level demographic data was retrieved from Guangzhou's 2010 census data. As a precaution given potential demographic changes between 2010 and 2016 (the year of the school dataset), we compared demographic composition at the town level with that calculated from a 1% population sampling survey in 2015 (which does not have neighbourhood-level data) and found no significant differences. Therefore, using the neighbourhood-level demographic data in 2010 should not impact the validity of our results.

We defined the secondary school–aged population as children from 12 to 18 years of age, because we were unable to distinguish the junior high school–aged population (aged 12 to 15) from the senior high school–aged population (aged 15 to 18) from the 2010 census data. According to the Guangzhou Municipal Government (2011), the spatial distributions of the junior and senior high school–aged populations are similar in the city. Therefore, our age definition of the secondary school–aged population should not challenge our conclusions pertaining to accessibility of secondary schools.

School characteristics. Table 1 shows the statistics for secondary schools in Guangzhou. These schools are divided into two types: key schools (both provincial and municipal) and regular schools. In total there are 510 secondary schools, including 45 key schools and 465 regular schools. The total enrollment size is 160,764 students; key schools account for 13% of this enrollment. As discussed previously, the key schools are more privileged in terms of their teaching facilities, faculty qualifications, and student academic performance (Xie and Wang 2006; Wang and Gu 2012).

Key schools demonstrate strong spatial concentration. Most key schools are located in the four districts of the inner city (Figure 2b), whereas regular schools are more evenly distributed (Figure 2a). This pattern indicates better access to key schools in the inner urban area.

Population characteristics. The school-aged (12 to 18 years old) population accounts for about 6% of the total population of Guangzhou. The inner suburb area has a larger share of the school-aged population, while neighbourhoods in the inner city and outer suburb area have less school-aged population. One exception is Zengcheng, which is a former county that has been recently incorporated into the Guangzhou municipality (Figure 3).

We used six factors comprising 19 indicators from the 2010 census data to measure the socioeconomic status of a neighbourhood (Table 2). More specifically, the six factors consider the

Table 1
Statistics for secondary schools in Guangzhou.

		Enrollment size				
Type	**Number of schools**	**Total**	**Mean**	**SD**	**Min**	**Max**
Key school	45	21,153	470.07	281.47	106	1,094
Regular school	465	139,611	301.54	182.99	50	1,893
Total	510	160,764	316.46	199.22	50	1,893

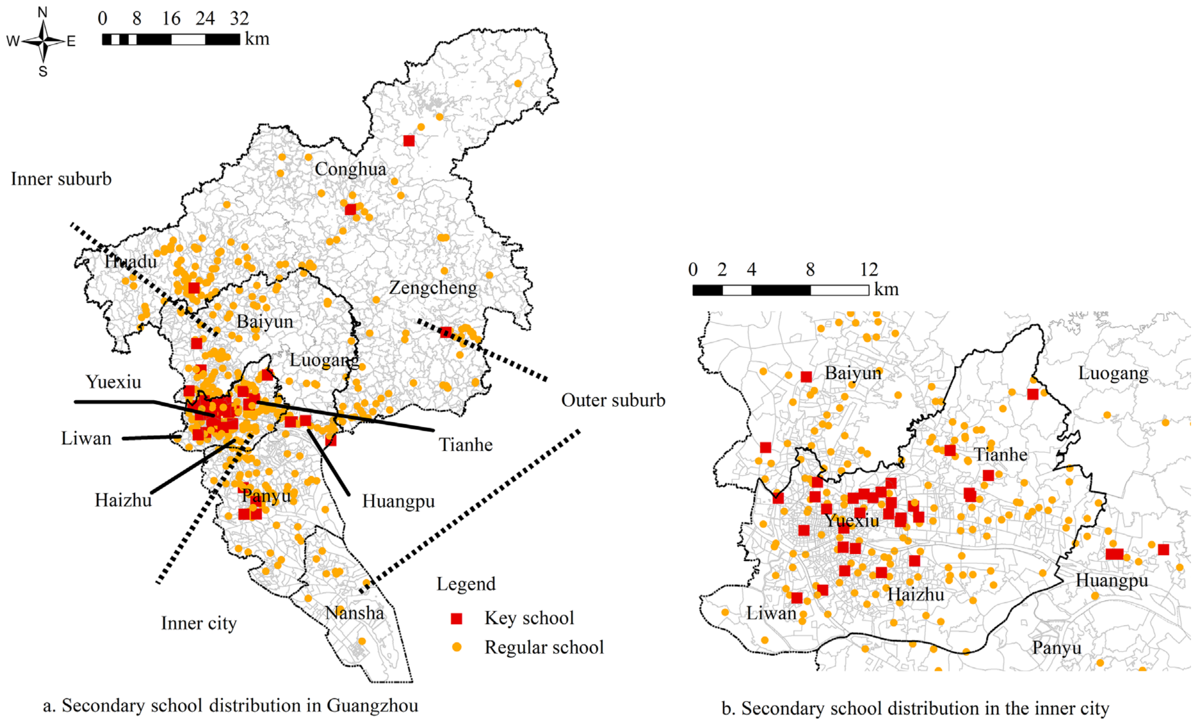

Figure 2
Spatial distribution of secondary schools.

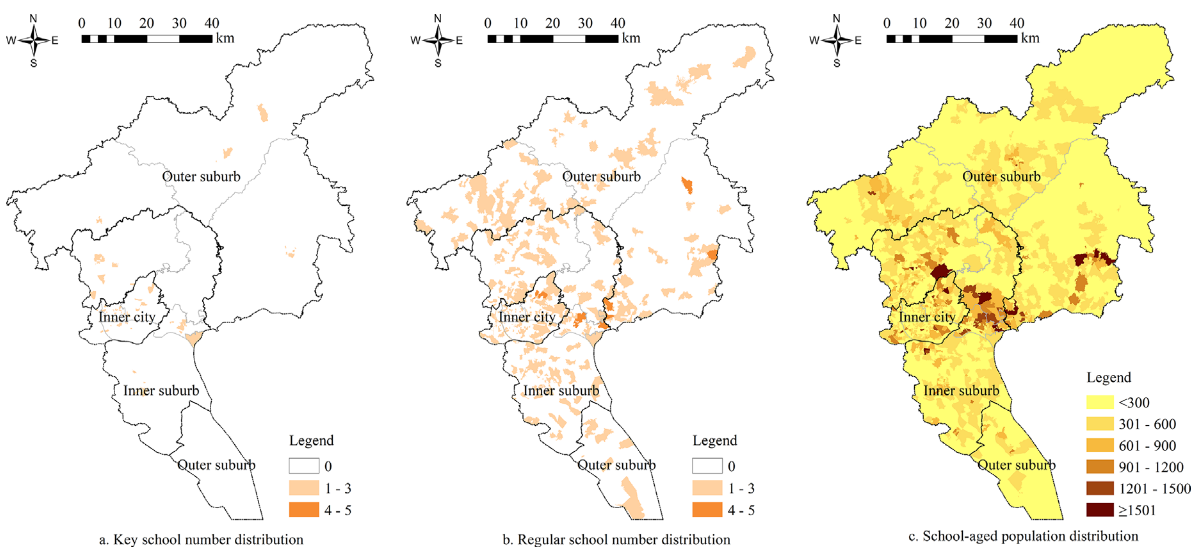

Figure 3
Spatial distribution of school number and school-aged population.

Table 2
The six socio-economic factors included in the model.

Factors	Variables	Description
Residence status	Local	Percentage of local population
	Migrant	Percentage of migrant population
Household registration	Urban	Percentage of population with urban household registration status
	Rural	Percentage of population with rural household registration status
Educational attainment	High	Percentage of population with educational attainment of college degree or above
	Medium	Percentage of population with educational attainment of senior secondary school or equivalent, and below college degree
	Low	Percentage of population with educational attainment of junior secondary school education or below
Housing tenure	Purchased commodity housing	Percentage of commodity housing owners
	Purchased reform housing	Percentage of reform housing owners*
	Self-built housing	Percentage of self-build housing owners
	Rental housing	Percentage of tenants
Profession	Farmer	Percentage of farmers
	Industrial worker	Percentage of industrial workers
	Public sector employees	Percentage of public sector employees
	Entrepreneur	Percentage of entrepreneurs
Income source	Salary	Percentage of recipients of a salary
	Retirement pension	Percentage of recipients of a retirement pension
	Minimum livelihood security	Percentage of recipients of a minimum livelihood security allowance
	Financial income	Percentage of recipients of financial income

*Reform housing used to be public rental housing provided by public sector employers to their employees in the socialist era; this housing was sold to sitting tenants during housing privatization in the 1990s.

socio-economic composition of a neighbourhood's population regarding their residence status (local vs. migrant); household registration status (urban vs. rural); education attainment (high, medium, or low); housing tenure (purchased commodity housing, purchased reform housing, self-built housing, or rental housing); occupation (farmer, industrial worker, public sector employee, or entrepreneur); and income source (salary, retirement pension, minimum livelihood security, and/or financial income). Interested readers may refer to Fu et al. (2015) and Fu (2015) for definitions of types of housing and occupations.

In the regression analysis, one cannot include all measures of the six socio-economic factors in one model due to multicollinearity issues. We thus only included variables denoting the percentages of *local, urban*, *purchased commodity housing, purchased reform housing, self-built housing, industrial worker, public sector employee, entrepreneur, recipient of salary,* and *recipient of retirement pension.* A principal component score of educational attainment is used as a measure of the education level of residents in a neighbourhood. The statistical model included variables for city zones (inner city as the reference group) to control for spatial variations.

Table 3 summarizes the demographic attributes of the population in Guangzhou in terms of the six factors. The inner city had a higher concentration of urban population and people with high or medium educational attainment. It also had a higher concentration of people who were homeowners of commodity housing or reform housing, public-sector employees or entrepreneurs, and pension recipients. The inner suburb area had higher percentages of migrants, tenants, industrial workers, and salary recipients. The population with rural household registration, those with low educational attainment, self-built house owners, farmers, and recipients of minimum livelihood subsidies or salary tended to be located in the outer suburbs.

Method

We used 2SFCA to examine secondary school accessibility. This approach can account for both the size (enrollment number) and quality (key or

Table 3
Profile of the population in Guangzhou.

Population groups	Inner city %	Inner suburb %	Outer suburb %	Whole city %
Residence status				
Local	52.7	40.9	67.2	51.6
Migrant	47.3	59.1	32.8	48.4
Household registration				
Urban	75.6	41.9	23.5	51.4
Rural	24.4	58.1	76.5	48.6
Educational attainment				
High	16.1	10.0	4.0	11.2
Medium	42.2	31.5	23.3	34.0
Low	41.7	58.5	72.7	54.8
Housing tenure				
Purchased commodity housing	31.7	19.3	25.1	25.9
Purchased reform housing	22.7	6.0	4.0	13.3
Self-built housing	4.0	14.3	53.3	16.2
Rental housing	41.6	60.4	17.6	44.6
Profession				
Farmer	0.5	4.7	18.6	6.3
Industrial worker	36.0	60.3	54.1	50.8
Public sector employees	31.0	15.8	11.3	19.9
Entrepreneur	32.4	19.2	15.9	23.0
Income source				
Salary	74.8	90.2	93.1	84.3
Retirement pension	22.4	7.1	4.4	13.0
Minimum livelihood security	0.4	0.4	1.1	0.5
Financial income	2.5	2.3	1.5	2.2

regular) of schools, which vary substantially in a Chinese city.

Figure 4 shows the concept of 2SFCA calculating school accessibility. Specific steps are elaborated as follows. First, we determined a threshold distance (d_0) to define the supply and demand catchment areas for secondary schools. Because no official sources of defined catchment areas are available, we needed to define the catchment areas following the principles specified in the Chinese Code of Urban Residential Areas Planning & Design (GB 50180-93). This principle (revised in 2002) advises that a neighbourhood with a population of 30,000 to 50,000 should have one designated secondary school. The Department of Education of Guangdong Province uses a thousand-person index to determine the optimal school size. Based on the thousand-person index, a quota of at least 50 junior secondary students enrolled should be designated

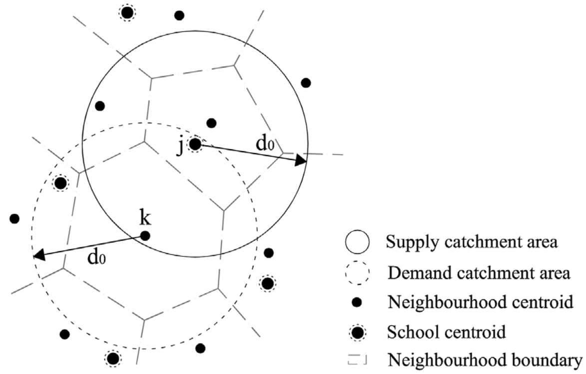

Figure 4
Concept of a two-step floating catchment area method (2SFCA).

to every thousand residents. As such, it is estimated that the average size of a secondary school is about 1,500 to 2,500 students. According to the population density of the city districts, we estimated that the average distance served by a secondary school in Guangzhou is between 3 km and 7 km: the distance tends to be shorter for the inner city with denser neighbourhoods and longer for the outer suburb with larger and less-populated neighbourhoods.

In order to substantiate our choice of the distance range (3 km to 7 km), we tested threshold distances of 2, 3, 5, 7, 10, and 20 km, respectively. The results suggested that 2 km is too small, which could leave some neighbourhoods without any school catchment, while the 10 km to 20 km threshold is too large, which may cause too much overlay. In the end, we decided to use 3 km, 5 km, and 7 km as threshold distances to calculate accessibility in inner cities, inner suburbs, and outer suburbs, respectively.

Once the threshold distance was determined, it was possible to draw the catchment areas for secondary schools (Figure 4). The plotted catchment areas were assumed to be circular since the actual catchment areas of secondary schools are relatively small compared to the entire city area.

Following the second step, we calculated the supply-to-demand ratio of each secondary school based on Formula (1) as:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \le d_0\}} G(d_{kj}, d_0) p_k} \quad (1)$$

where R_j is the supply-to-demand ratio of the supply catchment area of secondary school j. S_j is the supply capacity (i.e., enrollment size) of secondary school j; P_k is school-aged population in neighbourhood k whose centroid is located in the supply catchment area of secondary school j; and $G(d_{kj},d_0)$ is estimated distance decay of secondary school j using the Gauss equation:

$$G(d_{kj}, d_0) = \begin{cases} \dfrac{e^{-\frac{1}{2}\times\left(\frac{d_{kj}}{d_0}\right)^2} - e^{-\frac{1}{2}}}{1 - e^{-\frac{1}{2}}}, & if \ \ d_{kj} \le d_0 \\ 0, & if \ \ d_{kj} \ge d_0 \end{cases} \tag{2}$$

where d_{kj} is the distance from the centroid of secondary school j to the centroid of neighbourhood k and d_0 is the predetermined distance threshold, which is 3 km in the inner city, 5km in the inner suburb, and 7km in the outer suburb, respectively.

The last step was to calculate school accessibility using the supply-to-demand ratio and the distance decay function as specified above:

$$A_k = \sum\nolimits_{j\in\{d_{kj}\le d_0\}} G(d_{kj}, d_0) R_j \tag{3}$$

$$A_g = \sum\nolimits_k \frac{P_{(k,g)}}{P_g} A_k \tag{4}$$

where A_k is school accessibility for neighbourhood k, which is the summation of R_j multiplied by the Gauss distance decay equation $G(d_{kj},d_0)$, as noted in equation (2). A_g is the school accessibility of population group g, which is the summation of A_k weighted by the share of population group g in neighbourhood k; $P_{(k,g)}$ is the number of population group g in neighbourhood k; and P_g is the total number of population group g. A higher value of school accessibility means better access to schools in an area or for a specific population group.

Finally, we used median regression models to assess the relationship between school accessibility and the socio-economic status of neighbourhoods. This method, as a special case of quantile regression, predicts the median rather than the mean of the outcome variable. We adopted this approach because the calculated accessibility is highly skewed (e.g., there is an excessive number of zeros in the key school accessibility indices since many neighbourhoods are located outside the key school catchment areas) and median regression is particularly useful for handling the skewed outcome variable (Jalali and Babanezhad 2011).

Results

School accessibility

Table 4 summarizes the average school accessibility indices at the district level, and Figure 5 demonstrates the contribution of key school accessibility to overall school accessibility at the neighbourhood level. Key schools are remarkably less accessible than regular schools based on accessibility indices, with the latter being five times more accessible than the former.

Although school-aged students are roughly evenly distributed in the city, access to key secondary schools in different areas is highly skewed, with schools in the inner city being almost twice as accessible as those in the inner suburbs and 10 times more accessible than schools in the outer suburbs. Hot spots with high key school accessibility are mostly located in the inner city or its surrounding areas in the inner suburbs (Figure 5). In contrast, access to regular schools is relatively balanced across three areas—inner suburbs show slightly higher regular school accessibility (index = 200.59) compared to that in inner cities (index = 126.25) and in the outer suburbs (index = 158.66).

Given that these results highlight salient spatial disparities in the access to key schools in Guangzhou, a follow-up question is whether school accessibility is associated with a neighbourhood's socio-economic status. If such an association exists, inequity related to school accessibility is, per Truelove (1993), both horizontal and vertical.

Socio-economic gradient

In order to probe whether particular social groups have better access to key schools, we followed

Table 4
School accessibility index in three areas.

Area	District	School-aged population	Key school Enrollment size	Key school Accessibility index	Regular school Enrollment size	Regular school Accessibility index	All schools Enrollment size	All schools Accessibility index
Inner city	Haizhu	74,659	3,772	12.86	12,798	40.21	16,570	53.07
	Liwan	54,122	935	5.28	4,220	17.70	5,155	22.99
	Tianhe	69,851	3,354	8.34	13,501	34.30	16,855	42.64
	Yuexiu	58,142	4,764	19.64	8,043	34.05	12,807	53.69
	Total	**256,774**	**12,825**	**46.13**	**38,562**	**126.25**	**51,387**	**172.38**
Inner suburbs	Baiyun	123,980	1,398	12.44	21,954	75.05	23,352	87.49
	Huangpu	21,430	1,350	4.70	4,044	17.97	5,394	22.68
	Luogang	25,476	400	0.37	2,900	7.29	3,300	7.66
	Panyu	104,667	3,380	11.08	23,113	100.27	26,493	111.35
	Total	**275,553**	**6,528**	**28.59**	**52,011**	**200.59**	**58,539**	**229.18**
Outer suburbs	Conghua	63,856	450	1.30	7,905	27.93	8,355	29.23
	Huadu	62,419	950	2.14	19,297	62.41	20,247	64.55
	Nansha	17,310	0	0.00	3,150	13.68	3,150	13.68
	Zengcheng	100,473	400	0.67	18,686	54.64	19,086	55.31
	Total	**244,058**	**1,800**	**4.11**	**49,038**	**158.66**	**50,838**	**162.78**
Whole city		**776,385**	**21,153**	**78.83**	**139,611**	**485.50**	**160,764**	**564.33**

Formula 4 in the Method section to break down accessibility indices of key schools by a series of socio-economic variables. Results are given in Table 5. A higher percentage means a better chance to attend key schools for this group than for other groups. Across the city as a whole, advantaged groups with higher socio-economic status—that is, those with urban household registration status, individuals with high educational attainment, homeowners of commodity or reform housing, public sector employees or entrepreneurs, and recipients of retirement pensions—exhibited better access to key schools compared to their counterparts. In contrast, individuals with rural household registration, those with low educational attainment, owners of self-built housing, farmers, and recipients of minimum livelihood security had inadequate access to key schools.

These results seem to suggest an association between key school accessibility and the socio-economic characteristics of a neighbourhood. Following the descriptive analysis, we performed multivariate regression to further test the relationship. Statistical analysis results revealed a more compelling issue of spatial inequity for accessing key schools.

As Table 6 presents, accessibility to key schools is strongly and positively associated with neighbourhoods that have higher percentages of purchased reform housing, public sector employees, and pension recipients. Neighbourhoods with a higher percentage of self-built housing also show a better, albeit marginally significant, access to key schools —perhaps due to the concentration of self-built housing in the city centre, such as in urban villages. In contrast, neighbourhoods with more industrial workers have significantly lower access to key schools. Interestingly, other socio-economic characteristics of a neighbourhood, such as the percentage of local/urban population or education level of the population, do not show statistically significant associations with accessibility of key schools. These patterns indicate that key schools are most accessible to a small proportion of the existing population whose current location of residence was determined by the (previous) socialist redistribution system.

In contrast, the accessibility of regular schools was positively associated with the educational level of a neighbourhood and the percentages of purchased reform housing, industrial workers, public sector employees, and entrepreneurs. In other words, regular schools are more accessible to a

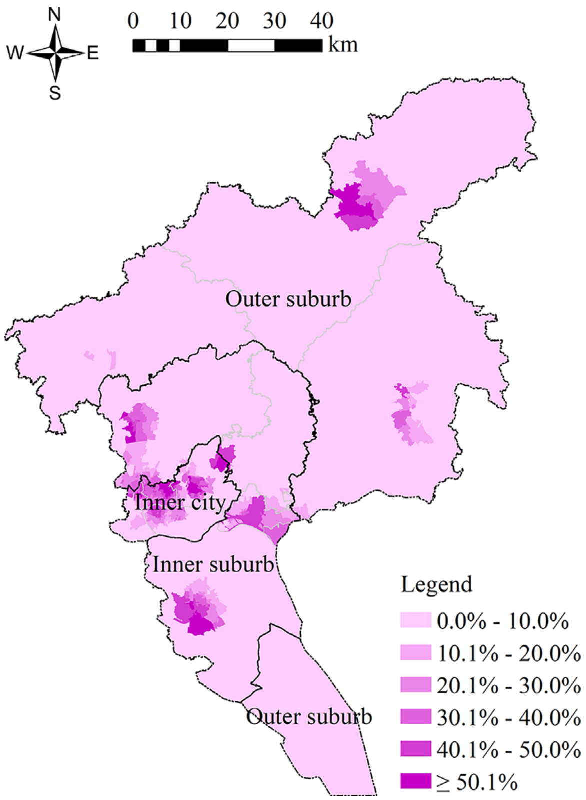

Figure 5
Percentage distribution of key school accessibility.

Table 5
Breakdown of key school accessibility indices by socio-economic variable.

Population groups	Accessibility index for population group	%
Residence status		
Local	0.036	51.0
Migrant	0.035	49.0
Household registration		
Urban	0.050	70.8
Rural	0.021	29.2
Educational attainment		
High	0.051	42.1
Medium	0.042	34.6
Low	0.028	23.3
Housing tenure		
Purchased commodity housing	0.051	31.2
Purchased reform housing	0.064	38.8
Self-built housing	0.014	8.7
Rental housing	0.035	21.3
Profession		
Farmer	0.005	4.1
Industrial worker	0.022	19.4
Public sector employee	0.048	41.5
Entrepreneur	0.040	34.9
Income source		
Salary	0.033	22.3
Retirement pension	0.056	37.5
Minimum livelihood security	0.024	16.4
Financial income	0.036	23.9

larger part of the urban population than key schools, although the socio-economic disparity in accessibility still exists for regular schools.

Overall, our results underscore a strong association between accessibility of secondary schools, especially key schools, and neighbourhood characteristics. Moreover, these associations also demonstrate the spatial inequity of school accessibility in Guangzhou. This pattern is particularly manifested in the mismatch between the demand and supply of school education. For example, the older population, such as owners of reform housing and recipients of retirement pensions, may have little demand for secondary education but yet have easy access to key schools, while the rest of the population possibly with a higher demand for secondary education have inadequate opportunities to access key schools. Spatial inequity also exists, to a lesser degree, for access to regular schools. Interestingly, residence status and household registration status did not show a significant association with secondary school accessibility.

Discussion and conclusions

The quality of their secondary education is of paramount importance for students' future well-being. While research has been undertaken on educational inequality, the topic of spatial equity of school access and how it may affect social equity remains understudied in a global context. Despite the expansion of compulsory education, China has witnessed increasing educational inequality. The existence of the key school system has played a critical role. With the aim of better understanding the spatial dimension of school accessibility, this

Table 6
Median regression results.

Socio-economic variables	Key school accessibility		Regular school accessibility	
	Coefficient	Standard error	Coefficient	Standard error
Local	−0.0042	0.0022	−0.0246	0.0192
Urban	0.0057	0.0079	−0.0373	0.0201
Education	−0.0010	0.0006	0.0095*	0.0042
Commodity housing	0.0015	0.0011	0.0154	0.0115
Reform housing	0.0451**	0.0085	0.0339*	0.0154
Self-built housing	0.0007*	0.0003	−0.0425**	0.0104
Industrial worker	−0.0061**	0.0019	0.2052**	0.0242
Public sector employee	0.0469**	0.0111	0.2579**	0.0327
Entrepreneur	0.0035	0.0046	0.1998**	0.0347
Salary	0.0102	0.0066	−0.0338	0.0930
Retirement pension	0.0656**	0.0161	−0.1137	0.0978
Location (ref: Inner city)				
– Inner suburb	0.0009	0.0043	0.1134**	0.0126
– Outer suburb	0.0007	0.0044	0.1420**	0.0113
Constants	−0.0106	0.0087	−0.0208	0.0861
Pseudo R^2	0.27		0.17	

* $p \leq 0.05$ ** $p \leq 0.01$

study addresses two empirical questions: first, what are the spatial patterns of secondary schools (regular vs. key) in Guangzhou? And second, what are the disadvantaged neighbourhoods with regard to regular or key school accessibility?

Overall, our results show that there is a biased spatial distribution of secondary schools in Guangzhou, which privileges certain neighbourhoods over others. First, school accessibility in Guangzhou varied between key schools and regular schools. Whereas regular schools had a relatively balanced spatial distribution, key schools were mainly concentrated in the inner city. Urban residents in the inner city of Guangzhou thus enjoyed better access to favourable educational opportunities. Second, adjusting for the spatial distribution of the school-aged population, school accessibility, especially accessibility of key schools, was significantly associated with socio-economic characteristics of a neighbourhood. Key schools appeared to be most accessible to neighbourhoods with more homeowners of reform housing, public-sector employees, and recipients of retirement pensions. In contrast, regular schools were more accessible to neighbourhoods with more better-educated residents, public sector employees, entrepreneurs, and industrial workers. Taken together, these results indicate that neighbourhoods with a high concentration of farmers and recipients of minimum livelihood security have poor access to both key and regular schools.

To decipher the spatial inequity in secondary school accessibility, we should note two mechanisms at work. On the one hand, a socialist mechanism appears to dominate key school accessibility and favours those who were in the socialist system. In this regard, winners in the reform era continue to benefit from easy school accessibility and better educational resources (Fu 2016). On the other hand, a market mechanism seems to influence regular school accessibility so that neighbourhoods with higher socio-economic status show better access to regular schools. Eventually, both mechanisms distribute educational resources according to parental socio-economic achievements rather than the needs and merits of students. While studies have shown that urban transformation and deepened market reform in China may reduce educational inequality (Jordan et al. 2014), this study challenges this conclusion and suggests that educational inequality in China could be perpetuating as long as favourable educational resources are unfairly distributed across space and social groups.

The Guangzhou municipal government has made great efforts to reduce educational disparity through school reforms since 2000, such as dismantling the key school system and expanding compulsory education. Despite some positive impacts on enhancing the overall accessibility to secondary schools, this study nevertheless highlights the persistent inequity in accessing key schools. While this study is limited to Guangzhou, the substantial disparities between key and regular schools in attracting good teachers, talented students, resources, and funding are relevant to other cities in China. Unless this hierarchical design of school systems is adequately addressed, the spatial inequity in secondary education in China will persist.

With regard to policy recommendations, we believe the city government can adopt different approaches to address the issue of spatial inequity. First, it can enhance the access to key schools by relaxing catchment area restrictions and providing better public transportation services. Second, it can reduce the gap in education quality between regular and key schools by increasing educational expenditure in regular schools. Third, it can adjust the skewed spatial distribution of schools across different urban areas through more holistic urban planning. Particularly, as more people move to the inner suburbs as part of the process of suburbanization, possible measures could include matching the allocation of schools with projected population growth at the neighbourhood level. Finally, the city government can provide additional financial support to the disadvantaged, such as families of farmers, migrants, and recipients of minimum livelihood security, so that their children may overcome the spatial barriers and have better access to educational resources.

Some limitations of our research should be acknowledged. First, the temporal mismatch of demographic data in 2010 and school location data in 2016 could affect our results. Yet we should also note that the demographic composition at the town level has not changed significantly according to the 2010 census and 2015 mini-census (for which only town-level statistics are available). Second, the threshold distance used in our research model did not consider more nuanced factors such as travel mode, school timetable, and traffic congestion. Third, while the spatial inequity in education in Guangzhou is relevant to other cities in China, more empirical studies based on other cities are needed to reveal a more comprehensive picture of school accessibility. Finally, since this research draws on aggregate data, it is subject to the ecological fallacy and multi-level analyses combining both aggregate and individual data are warranted for future studies.

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