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Spatial inequality of job accessibility in Shanghai: A geographical skills mismatch perspective

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ABSTRACT

This study explores the spatial inequality of job accessibility in urban China, focusing on geographical skills mismatch in Shanghai. Our results suggest that geographical skills mismatch should be a critical concern in measuring job accessibility because the urban villages create residential sites for low-skill workers in central Shanghai. Based on the job accessibility index considering geographical skills mismatch, the floating population has high job accessibility in the periphery of the central urban area because there are affordable housing prices. The spatial distribution of the registered population's job accessibility still follows the core-periphery pattern. The spatial mismatch between the job centers for floating and registered populations might enlarge the segregation between them. The path analysis reveals that the housing/rent market, urban structure, and education attainment collectively shape job accessibility through residential segregation. Furthermore, path analysis manifests that high-skill people, mainly living in the central urban area, have significantly higher job accessibility. The polycentric development fails to create self-contained job centers for low-skill people. Future policies should pay attention to connecting the low-skill workers and their job markets through public rental housing or improving the public transit system.

1. Introduction

Poor job accessibility usually refers to the disconnection between people and job opportunities (Kain, 1992). It contributes to increasing commuting and living costs, further intensifying urban inequality and harming sustainable urban development. The socioeconomically disadvantaged population is more likely to have poor job accessibility because they are usually segregated and discriminated against in the job market and housing market (Gobillon, Selod, & Zenou, 2007). Thus, the existing literature pays particular attention to disadvantaged people such as minorities and poor migrant workers (Fan, Allen, & Sun, 2014; Fernandez, 2008; Hu, 2015, 2019). Regarding this attention to low-income and poorly educated people's poor job accessibility, physical disconnection should not be the only cause. Alternatively, Stoll (2005) proposed a geographical skills mismatch hypothesis that could explain why low-skill workers have poor job accessibility from a perspective of educational attainment.

Since most of the existing experiences on job accessibility are derived from WesternStoll (2005) countries' experience, Chinese cities, which have experienced urban expansion and rising commuting time, are still unstudied (Sun, Ermagun, & Dan, 2017). Chinese cities are ignored mainly because the *Danwei* system creates a highly self-contained community for workers. The *Hukou* system also limits people's mobility, and people would not like to leave their hometown for better job opportunities as a floating population. However, the large metropolitans in China have achieved significant development and now provide job opportunities with high salaries, which attract many floating populations (Liang, Li, & Ma, 2014). On the other hand, the *Danwei* system is diminishing, and the booming housing market contributes to high housing prices (Wang & Chai, 2009). The high housing price significantly decreases low-income floating migrant workers' housing affordability (Chen, Hao, & Stephens, 2010), decreasing their job accessibility (Fan et al., 2014; Liu, Huang, & Zhang, 2018).

Most empirical studies in China have explained low-income migrant workers' poor job accessibility via the imbalanced jobs-housing relationship, primarily influenced by urban structure (Fan et al., 2014; Wang, Song, & Xu, 2011; Zhou, Wu, & Cheng, 2013). Traditionally, urban China is highly centralized, but the uneven distributions of jobs and population are mainly created during suburbanization. In the suburban areas, the job opportunities are highly concentrated in the

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development zones that provide limited space for residence (Zhou, Wang, Cao, & Wang, 2017). On the other hand, there are many urban villages in the central urban area where migrating workers reside in the central urban area. These migrating workers are usually poorly educated and unqualified for the high-skill jobs in urban centers, and their jobs have already been suburbanized during industrial upgrading. Thus, job accessibility in urban centers is overestimated by previous studies, which also suggests the existence of a much more complex mechanism—the geographical skills hypothesis (Stoll, 2005).

This article develops a measure of job accessibility regarding the research gaps considering both physical disconnection and geographical skills mismatch between population and jobs. With this new job accessibility index, we empirically examine the following issues cornering job accessibility inequality in Shanghai, China: 1) To what extent, geographical skills mismatch contributes to the inequality of job accessibility in Shanghai? 2) What are the spatial patterns of job accessibility for the floating and registered population in Shanghai? 3) What are the relationship between job accessibility, residential segregation, people's sociodemographic status, and the housing market? This study fills the gap in explaining job accessibility from the perspective of geographical skills mismatch and further identifies the mechanism of job accessibility in urban China.

2. Job accessibility, skill mismatch, and the Chinese context

The spatial mismatch is generally used to explain poor job accessibility (Fernandez, 2008; Grengs, 2010; Hu, 2015; Wang et al., 2011). However, spatial mismatch is regarded as an ill-defined concept in that it is a complex social phenomenon (Grengs, 2010). It contains a wide range of issues, such as the population and jobs, transportation system, and the housing market. The existing literature tries to identify the mechanism of spatial mismatch and the vulnerable population groups regarding these related issues. Early research on spatial mismatch mainly focuses on African Americans' poor job accessibility (Kain, 1992). Further studies look beyond African Americans to include all the low-income minorities and emphasize the impacts of socioeconomic status and car ownership (Fan, 2012). Thus, the low-income minority workers usually have poor job accessibility according to the U.S. experience (Fernandez, 2008; Grengs, 2010; Hu, 2015, 2019; Kawabata, 2003).

Gobillon et al. (2007) explore the causes of poor job accessibility and shed light on discrimination's impact on minorities. They provided a comprehensive framework to explain minorities' poor job accessibility concerning distance, residential segregation, and working skills. Distance refers to the physical disconnection between people and jobs, which is the outcome of plants' suburbanization (Kain, 1992). This disconnection results from changing space and the minorities' poor housing affordability, preventing them from moving with plants (Levin, 1998). Also, residential segregation limits minorities' mobility and increases minorities' costs in accessing job opportunities, and employers may discriminate against the segregated workers (Gobillon et al., 2007). Furthermore, insufficient involvement in the segregated workers' social interaction with local people and culture contributes to low working efficiency (Selod & Zenou, 2006).

On the other hand, the African American workers reside in the central urban area where the high-skill job opportunities are located. Evidence suggests that African American workers are more likely to apply for jobs in the central urban area than suburban areas (Holzer & Reaser, 2000). Thus, their poor job accessibility is more than only physical disconnection. They have poor job accessibility because they cannot access the job opportunities fitting their working skill and education level. Stoll (2005) makes a geographical skills mismatch hypothesis to explain the poor job accessibility of low-income and low-skill workers in the central urban area. In this framework, less-educated minorities are disconnected from the mainstream economy because they have to stay in the central urban area and cannot access high-skill jobs.

In China, the highly concentrated urban planning and the *Danwei* system, which provide workers with residential sites close to their workplaces, are more resistant to the job accessibility problems (Fan et al., 2014; Wang & Chai, 2009). However, as the *Danwei* system is diminishing in China for a free housing market, skyrocketing housing prices in China contribute to poor housing affordability (Hui & Yue, 2006; Li, Wei, & Wu, 2019a; Zhang, Jia, & Yang, 2016). Poor housing affordability would undermine the co-location hypothesis because people cannot freely select their residential sites. In urban China, people's housing choice is mostly limited by the free housing market and poorly developed public housing provision system (Zhou et al., 2017).

Besides the commercial housing market, urban villages have regularly become a complement of residential choices to accommodate low-income people's housing needs (Zhu, 2017). However, the job opportunities surrounding these urban villages in the central urban area are high skill-jobs, and urban villages usually have poor public transit access (Fan et al., 2014). On the other hand, public rental houses are suggested to have poor job accessibility, which further contributes to the physical disconnection between jobs and low-income people (Chen, Zhang, & Lu, 2015).

Due to a massive number of rural population flowing into large cities for better job opportunities, studies in urban China have paid particular attention to low-income migrant workers in the large metropolitan areas (Fan et al., 2014; Zhao & Howden-Chapman, 2010; Zhou et al., 2013). The floating population takes up a large portion of the total population in the large metropolitan areas in China, such as Beijing and Shanghai (Liang et al., 2014). They are disadvantaged in socioeconomic status and cannot benefit from the government policies on housing or job searching because of the *Hukou* system, which decreases their proximity to job opportunities (Fan et al., 2014; Luo et al., 2018). Furthermore, the floating population has poor social and cultural integration and is suggested to be residentially segregated (Liu et al., 2018).

On the other hand, Chinese cities are experiencing rapid urban expansion (Li, Wei, & Huang, 2014), and there are job sub-centers in the suburban areas (Cheng, Liu, He, & Shaw, 2017; Lv, Zheng, Zhou, & Zhang, 2017; Yang et al., 2017). However, the co-location hypothesis fails in practice, and few people move following job opportunities (Wei, Bi, Wang, & Ning, 2016; Zhu, 2016; Zhu, Zhao, Wang, & Al Yammahi, 2017). These decentralized job opportunities are highly concentrated in the development zones with single land use planning for industry (Zhou et al., 2017). Thus, the residential sites with good access to the development zones' jobs are limited, and the poor migrant has to rely on the shuttle bus or other public transportation to access these jobs.

In summary, in the studies that explore the spatial pattern and underlying mechanism of job accessibility in urban China, the explanation of geographical disconnection remains prevailing. Theoretically, geographical skills mismatch is rarely considered in the literature, which inevitably misses residents' unique socioeconomic characteristics in urban villages. Regarding people's rising commuting time (Sun et al., 2017) and the residential segregation (Li & Wu, 2008) in Shanghai, geographical skills mismatch has become the major contributor to the city's poor job accessibility. There has been an urgent need to look beyond the physical disconnection and turn to a geographical skills mismatch perspective.

3. Job accessibility index: A skill mismatch approach

Methodologically, early research usually uses a population-job ratio in a specific region as a quantitative measure because job accessibility describes the physical connection between people and jobs (Ellwood, 1986). Further studies have improved the quantitative measures, such as incorporating spatial effects (Shen, 1998) or considering different travel modes (Grengs, 2010). However, the limitations still exist.

One of the most significant limitations is that the model cannot simultaneously capture job competition and people's choices (Shen,

1998; Merlin & Hu, 2017). That is because the calculation of a population-job ratio requires a predefined analytical zone, such as census tracts or buffer areas. However, the analytical zones for people's choice of jobs and job competing are different. Thus, scholars try to use the two-step floating catchment area (2SFCA) method to capture job accessibility (Hu & Downs, 2019; Tao, Zhou, Lin, Chao, & Li, 2020). This method separately calculates the supply-demand ratio for supply sites (labor force) and demands sites (labor market), and uses the cumulative method to get the final estimation. On the other hand, few models try to consider geographical skills mismatch. The primary barrier to estimate geographical skills mismatch is limited access to the job data with education or skill requirements. As the open-source data is getting popular in urban research, scholars can quickly obtain detailed information such as housing prices, urban amenities, and job opportunities that can help estimate geographical skills mismatch (Li, Wei, & Wu, 2019 a&b; Wu, Huang, Sun, & An, 2016).

An improved job accessibility index considering skill mismatch is generated based on the 2SFCA method regarding these limitations. Here are two steps for the general expression of the 2SFCA method, using job accessibility as an example:

Step1: Get the supply-demand ratio for workplace *j*For the workplace *j*, find every residential site *k* within a predefined catchment zone to calculate the supply-demand ratio R_i as formula 1:

$$R_j = \frac{Job_J}{\sum Pop_k * W} \tag{1}$$

Job_j refers to the number of job opportunities in workplace *j*, and Pop_k refers to the number of population for each residential site *k* within the catchment area. *W* is the spatial weight calculated based on the catchment zone which is usually represented by the distance between each job opportunity and workplace.

Step2: Calculate the job accessibility index for the residential site *i*.

For residential site *i*, find every workplace *k* within the catchment zones and calculate the job accessibility index JA_i

$$JA_i = \sum R_k * W \tag{2}$$

In this formula, R_k is the supply-demand ratio in workplace *k*.

In this formula, we extend the weight matrix by considering geographical skills mismatch. In this paper, the education level and salary are employed as indicators of working skill because they can comprehensively reveal the working skill-related issues, such as social/interactive skills or working experience (Hu, 2015; Kawabata, 2003; Stoll, 2005). Thus, we combine physical distance, salary distance, and education distance to get the weight matrix (W) as follow, which could better fit the context of job accessibility:

$$W = d_{edu} * d_{salary} * d_{dist} \tag{3}$$

In this formula, d_{edu} is a dummy variable to ensure the job seeker's education level meets the job opportunity requirement. d_{salary} is to make sure that the job opportunity's salary meets the job seeker's expectation and job. If the job opportunity's salary is the same as the job seeker's expectation, it means that the job best fits the job seeker. If not, the higher or lower salary would decrease the job opportunity's fitness to the job seeker. People could generally find job opportunities with a twenty percent salary above or below expectation (Kuptsch & Goux, 2010; Zweig & Han, 2010). Based on this idea, d_{salary} is defined as follows.

$$d_{salary} = \begin{cases} 1 - \left|\frac{Salary_i - Salary_j}{Salary_i}\right|, \left|\frac{Salary_i - Salary_j}{Salary_i}\right| \le 0.2 \\ 0, \quad 0.2 < \left|\frac{Salary_i - Salary_j}{Salary_i}\right| \end{cases} \tag{4}$$

$Salary_i$ refers to the job seeker's expectation, and $salary_j$ is the salary of the job opportunities.

The spatial distance d_{dist} is calculated based on the spatial weight matrix in Luo and Qi's (2009) enhanced the 2SFCA method. This method defines catchment zones with 1-h travel time and classifies the catchment zones into three sub-zones based on travel time, 0–15 min, 15–30 min, and 30–60 min. The spatial weight *W* for each part is calculated using Gaussian weight $f(d) = e^{-d^2/\beta}$. Notably, the value of 2SFCA is sensitive to the impedance coefficient β, which could vary according to the research context. Thus, we employed the spatial access ratio method (Wan, Zhan, Zou, & Chow, 2012), an improved 2SFCA method, which could vastly reduce the impedance coefficient's impact. The spatial access ratio is calculated as the ratio between a residential place's value and all residential places' mean value.

Thus, the improved 2SFCA method in this study concerning skill mismatch could be summarized as follows:

The first step is the same as the traditional 2SFCA method, while the spatial weight is estimated using Luo and Qi (2009) 's method. Job_j is the number of job opportunities in workplace *j,* and Pop_k is the number of job opportunities in census tract k

$$\begin{aligned} R_j = & \frac{Job_j}{\sum Pop_k * W_1\{k \in (\text{dist} < 15\text{min})\}} \\ & + \sum Pop_k * W_2 \Big\{ k \in (15\text{min} < \text{dist} < 30\text{min}) \\ & + \sum Pop_k * W_3 \Big\{ k \in (30\text{min} < \text{dist} < 60\text{min}) \end{aligned} \tag{5}$$

The second step is to calculate the supply-demand relationship for workplace *i*

$$\begin{aligned} JA_i = & \frac{1}{\sum R_k * Job_k * d_{edu,ik} * d_{salary,ik} * W_1\{k \in (\text{dist} < 15\text{min})\}} \\ & + \sum R_k * Job_k * d_{edu,ik} * d_{salary,ik} * W_2 \Big\{ k \in (15\text{min} < \text{dist} < 30\text{min}) \\ & + \sum R_k * Job_k * d_{edu,ik} * d_{salary,ik} * W_3 \Big\{ k \in (30\text{min} < \text{dist} < 60\text{min}) \end{aligned} \tag{6}$$

W_1, W_2, and W_3 values are determined based on which sub-zones they are located in. Job_k is the number of the same job opportunities for job_k. $d_{edu,ik}$, and $d_{salary,ik}$ separately represents the distance concerning education and salary between personal *i* and job *k*. The travel time between job opportunities and people's residential sites are estimated using network analysis in Arcmap.

4. Data and methodology

4.1. Study area

This study includes sixteen districts in Shanghai. Chongming district is a separate island, and it is not included in this study to guarantee the study area is geographically contiguous. Wei et al. (2016) classified these districts into four different regions—namely traditional city proper area (Huangpu, Jing'an), extended central city area (Xuhui, Changning, Putuo, Zhabei, Hongkou, Yangpu), inner suburban area (Pudong, Minghang, Baoshan), and outer suburban area (Jiading, Qingpu, Songjiang, Jinshan, Fengxian). Subdistrict (Jiedao, Xiang, Zheng) is the most basic administrative and geographical unit in China for population statistics (Fig. 1). Shanghai had 23,019,148 people according to the population census in 2010, and over forty percent of the total population is a floating population. In urban China, the floating population is a vital driver of urbanization and urban development (Luo et al., 2018). Thus, improving the living and working environment for the floating population is critical for Shanghai's sustainable development.

In recent years, urban land in Shanghai has expanded rapidly, and suburbanization is accelerated. As the housing price keeps rising in the traditional central urban area, some people move out of the city center to reside in the expanded central urban area. Thus, many people live in the expanded central urban area and work in the traditional central urban area. On the other hand, the job opportunities in the suburban area mainly located in the development zones, which is suggested to be jobs-housing imbalanced because of the single land use for industry within the development zones (Zhou et al., 2017). Because of the uneven

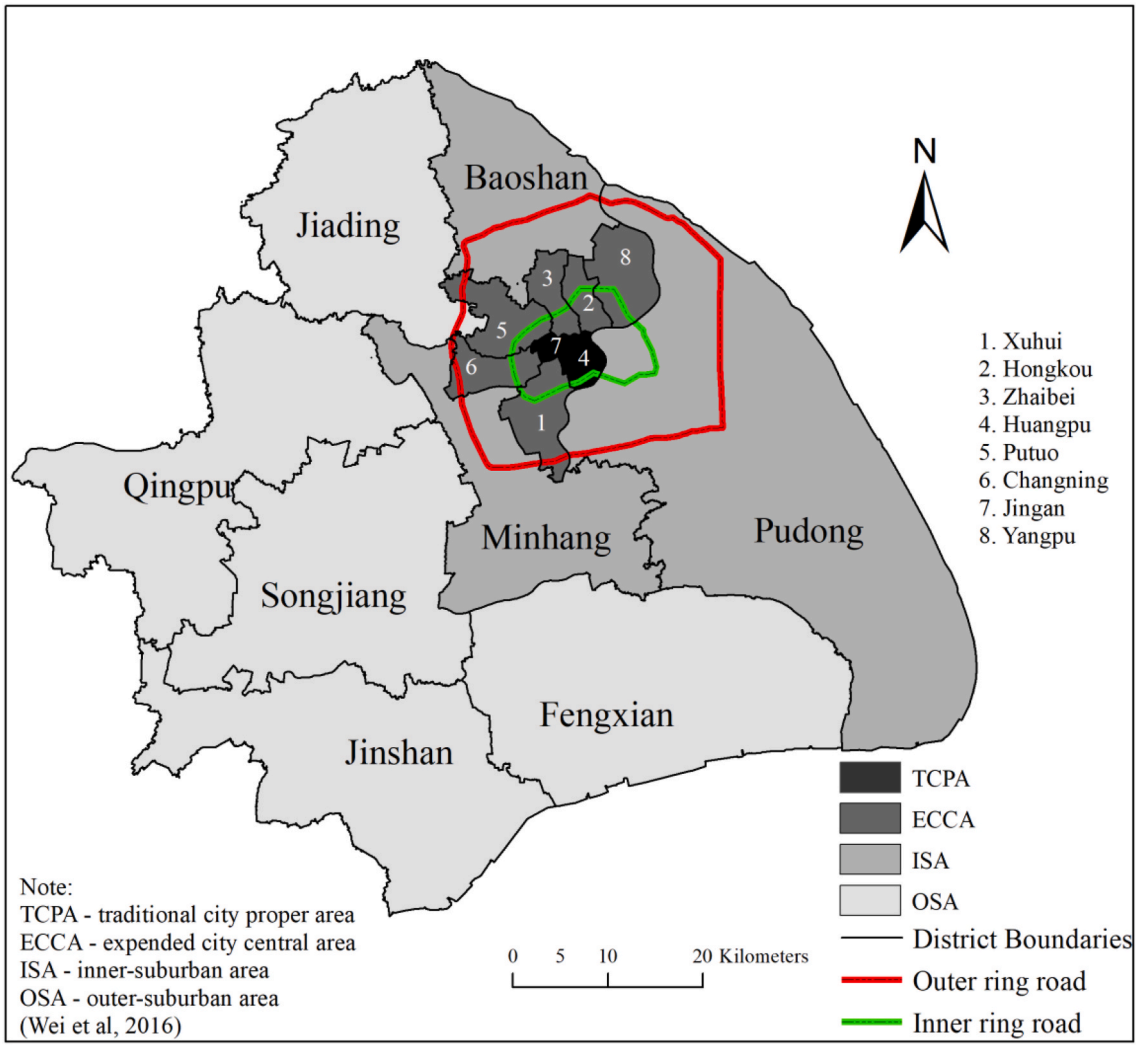

Fig. 1. Districts and ring roads in Shanghai.

distribution of job opportunities and population in Shanghai, people's commuting time keeps rising in recent years. It is reported that the commuting distance has increased from 6.8 km in 2004 (SCCTPI, 2005) to 8.8 km or 39 min' travel in 2016 (Sun et al., 2017). Thus, decreasing job accessibility is a challenge to people in Shanghai, particularly for the floating population with fewer housing choices than the registered population.

4.2. Data

The population census in 2010, population monitoring data in Shanghai in 2013 and the job opportunities data in 2017 from 51job.com are employed to estimate geographical skills mismatch. 51job.com is the most popular platform for people to search for job opportunities and is also a reliable employment data source for research (Li, Wei, & Wu, 2019b; Sun, Zhen, Lobsang, & Li, 2019). The dataset contains the locations of the job opportunities, salary, and requirements for education level. Due to the data availability, there is a time gap between the population dataset and job dataset that used in this study. Population census data in 2010 and the population monitoring data in 2013 are the most recent official data sources, while open data sources of new job opportunities are available recently. However, this gap will not insignificantly affect our analysis and findings. According to the comparison between open datasets and census data, the spatial configuration of Shanghai's population and job opportunities has shown a stable pattern since 2010, according to the comparison between open datasets and census data (Li et al., 2019b; Xiao, Wei, & Li, 2021).

The population monitoring data is collected based on Shanghai's communities, representing the Shanghai population. This data is obtained using two comprehensive surveys separately for the floating population (5,968 samples for 10,640,346 people) and registered population (7,893 samples for a total of 11,589,414 people) the questions for sociodemographic status, accessibility to health care, etc. The floating population survey includes some additional information, such

Table 1
Descriptive statistics.

Sample Size	Registered Population		Floating Population	
	5170		5240	
	Mean	Variance	Mean	Variance
Job Accessibility	0.13	0.22	0.094	0.16
Education Level	4.67	1.55	3.88	1.59
Working years	14.75	11.63	5.18	4.37
Income	3496	3112	4172.70	3584.88
Housing value	57,885	22,153	43,537	16,872
Rent value	6705	3778	5768	3335
	Count		Count	
Inner ring road	1077		272	
Outer ring road	2953		1026	
Agriculture *Hukou*	/		1294	

as the locations of their hometowns and when they come to Shanghai.

Table 1 shows a summary of the population monitoring data. It suggests the floating population now has a high income because they take more intensive work than the registered population. The floating population is disadvantaged in education while they have a lower education level than the registered population. Examining the spatial distribution, we find that only a few floating populations live within the inner ring road, and most of them still live out of the outer ring road.

Furthermore, the relationship between job accessibility and housing/rent price is crucial in this paper. Lianjia.com, as one of the largest property trade platforms in China, provides the data of the housing/rent price, which has become a popular open data source for housing study (Li et al., 2019a&b). To estimate each household's housing/rent price, we generate a 1-km buffer and use the average housing/rent price. The general patterns of housing/rent prices in Shanghai are presented in Fig. 2. There is a gradient of housing prices from the core region to the suburban area because Shanghai is highly concentrated. The rent price is also high in the central urban area. But the decentralized job opportunities in the development zones and vocational villages might contribute to high rent in the suburban area.

4.3. Path analysis

The relationship between the influencing factors of job accessibility is intertwined, and some determinants do not directly influence job accessibility. For example, as the primary determinant of job accessibility in the literature (Kain, 1992), residential segregation is also influenced by people's education, urban structure, and housing affordability (Li & Wu, 2008). However, factors such as education also affect people's job accessibility. Existing knowledge of job accessibility cannot explain this intertwined relationship (Gobillon et al., 2007; Hu, Fan, & Sun, 2017; Zhao & Howden-Chapman, 2010). In this condition, the structural equation model is a powerful tool to reveal the intertwined relationship.

Path analysis is a structural equation modeling technique that can reveal direct and indirect dependencies among a set of variables (Wei, Xiao, Simon, Liu, & Ni, 2018). This study aims to identify the impacts of people's working skills and the urban structure factors such as housing price and urban spatial structure on job accessibility. However, there is no evidence that housing prices and ring roads directly influenced job accessibility. Still, they significantly contribute to residential segregation in Shanghai (Li & Wu, 2008), a critical determinant of job accessibility. Thus, residential segregation could be a mediator to explore the indirect effect of urban structure variables on job accessibility. This paper uses a dissimilarity index to reveal the residential segregation in the traditional central urban area, the expanded central urban area, the inner suburban area, and the outer suburban area based on district-level population data. In Eq.(7), $Dissimilarity_K$ is the dissimilarity index for region K, and f and r separately represent the floating population and registered population in subdistrict i within region K. n is the number of subdistricts in the region K.

$$Dissimilarity_K = \frac{1}{2} * \sum_{i=1}^{n} \left| \frac{f_i}{\sum_{i=1}^{n} f_i} - \frac{r_i}{\sum_{i=1}^{n} r_i} \right| \quad (7)$$

Based on the existing background about the determinants of job accessibility, we paint a conceptual diagram to reveal the causal relationship between the variables (Fig. 3). In this diagram, people's working skills and residential segregation are directly related to people's job accessibility. Working skills, Hukou status, and residential segregation are all interrelated, and at the same time, are influenced by urban structure factors (Li et al., 2019a). When we implemented this path analysis, people's working skills are specified into years, income, and education directly affect job accessibility. Four urban structure factors are considered: housing/rent price, rent, inner ring road, and outer ring road. Agriculture and non-agriculture *Hukou* status are only available for the floating population, influencing people's education and income. Two measures are used to capture job accessibility, and they are added into path analysis in two separate models. The first one uses job accessibility based on traditional spatial mismatch, which only considers physical distance. The other one uses job accessibility considering geographical skills mismatch, including education level and salary. The differences between these two models are expected to reveal the significance of geographical skills mismatch.

4.4. Spatial pattern of high-skill jobs and population

The traditional spatial mismatch hypothesis emphasizes the physical disconnection between job opportunities and population (Gobillon et al., 2007; Kain, 1992). The geographical skills mismatch describes the spatial mismatch between low-skill jobs and the low-skill population

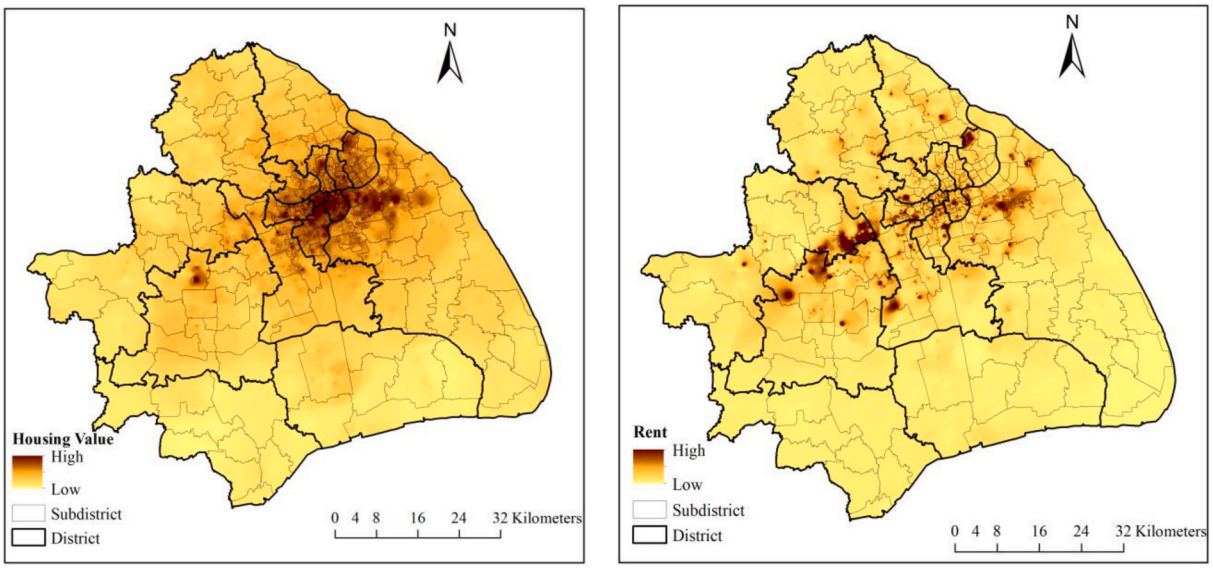

Fig. 2. Housing price and rent in Shanghai.

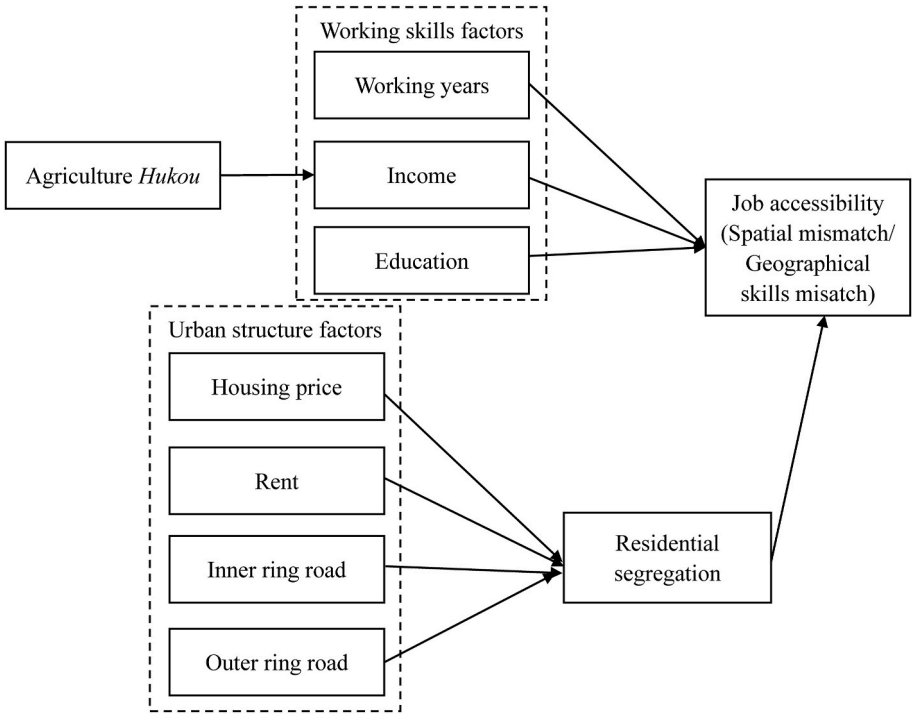

Fig. 3. The diagram for path analysis.

(Stoll, 2005). Thus, jobs and population's spatial distributions with different skills are highlighted in these two frameworks. This section examines the average salary and educational attainment for the floating population and registered population in all the subdistricts (Table 2).

The result suggests that the traditional central urban areas are still the high-skill job centers of Shanghai. Three districts in the expanded central urban area function as high-skill job centers, including Xuhui, Yangpu, and Changning. These districts are newly developed regions that attract many producer service jobs (Li et al., 2019b). Regrading working skills, job opportunities in the suburban area requires a lower education level. The distribution of job salary still follows the core-periphery pattern, and the urban periphery's job salary is much lower than the central urban area and the inner suburban area. Although the Pudong district is located in the suburban area, it owns a similar job salary. There is a high education level as the traditional urban center, Huangpu and Jin'an district, serving as a new high-skill job center in Shanghai.

Comparing the floating population and registered population's spatial distributions, we find a significant difference between the high-skilled floating population and the registered population. The central urban area is the residential center for the high-level registered population rather than the floating population. The Huangpu and Jin'an districts are the traditional urban center of Shanghai with extremely unaffordable and extremely high housing prices. Thus, the floating population's the only choice of residence in these two districts in the urban village, which is not preferred by the high-level floating

Table 2
Salary and education of job opportunities and population.

District	Job opportunities		Registered population		Floating population	
	Education	Salary(Thousand)	Education	Salary(Thousand)	Education	Salary (Thousand)
Traditional central urban area						
Huangpu	23.7%	9.18	47.8%	4.49	15.3%	8.19
Jing'an	23.7%	9.01	57.3%	5.59	15.4%	3.85
Expanded central urban area						
Xuhui	22.0%	8.92	57.6%	4.05	21.4%	4.85
Changning	22.8%	9.26	41.7%	3.59	30.8%	3.62
Putuo	17.8%	8.99	43.2%	3.59	20.0%	3.76
Zhabei	17.5%	8.60	52.2%	3.67	26.9%	3.82
Hongkou	19.7%	8.90	52.7%	4.25	7.7%	3.95
Yangpu	26.1%	8.98	40.5%	3.97	29.5%	4.48
Inner suburban area						
Pudong	25.0%	9.27	40.9%	3.87	26.1%	4.37
Minhang	18.5%	8.70	42.1%	4.01	36.4%	4.83
Baoshan	15.8%	8.16	42.0%	3.67	28.1%	4.21
Outer suburban area						
Jiading	16.3%	7.97	31.8%	3.31	14.0%	3.72
Qingpu	19.8%	8.07	38.9%	3.92	2.8%	3.33
Songjiang	16.6%	8.00	38.9%	3.61	21.9%	3.96
Jinshan	14.5%	7.28	39.1%	2.66	16.1%	4.01
Fengxian	17.4%	7.67	31.5%	3.26	3.8%	3.08

Note: Education level: percentage of the population with a college degree or above.

population. The registered population lives in these two districts because they already live there for decades, and most of them are not resettled during the demolition in China. Since people living in these two districts have good accessibility to good urban amenities and high-skill job opportunities, the high-level people would not move to other regions, while they still can afford the living expenditure.

There are three districts with high percentages of well-educated floating populations, including Changning, Yangpu, and Minghang. Among these three districts, Minghang is the residential center for the floating population. Minghang districts are closed to the Pudong, Xuhui, and Changning districts, promising future urban development and economic growth as financial centers or high-tech centers. Also, housing/rent prices are not high in these regions (Li, Wei, Wu, & Tian, 2019), which is much more affordable than the districts in the traditional central urban area. Thus, the well-educated floating population would be likely to reside in the Yangpu and Minghang districts.

So far, we find a spatial mismatch between the job centers for floating and registered populations. High-skilled registered populations would live close to the traditional urban center and the surrounding areas such as Putuo and Hongkou. The high-skilled floating population favors the newly developed districts in the inner suburban areas, the promising subcenters of Shanghai. Furthermore, we find that some regions have significant residential segregation between high-skilled registered and floating populations. For example, the residential center for the high-skill floating population, such as the Yangpu district, has a low percentage of the registered population. Over half of the Hongkou district's registered population has a high education level, while the floating population's value is only seven percent. The residential segregation between the high-skilled floating population and the registered population might contribute to the spatial inequality of job accessibility.

5. Job accessibility in Shanghai

5.1. Job accessibility and geographical skills mismatch

The geographical skills mismatch measured by our new job accessibility index and traditional spatial mismatch using a basic 2SFCA method is presented in Fig. 4. Fig. 4 presents the spatial mismatch and geographical skills mismatch for the registered population and registered population. The floating population and the registered population are examined separately.

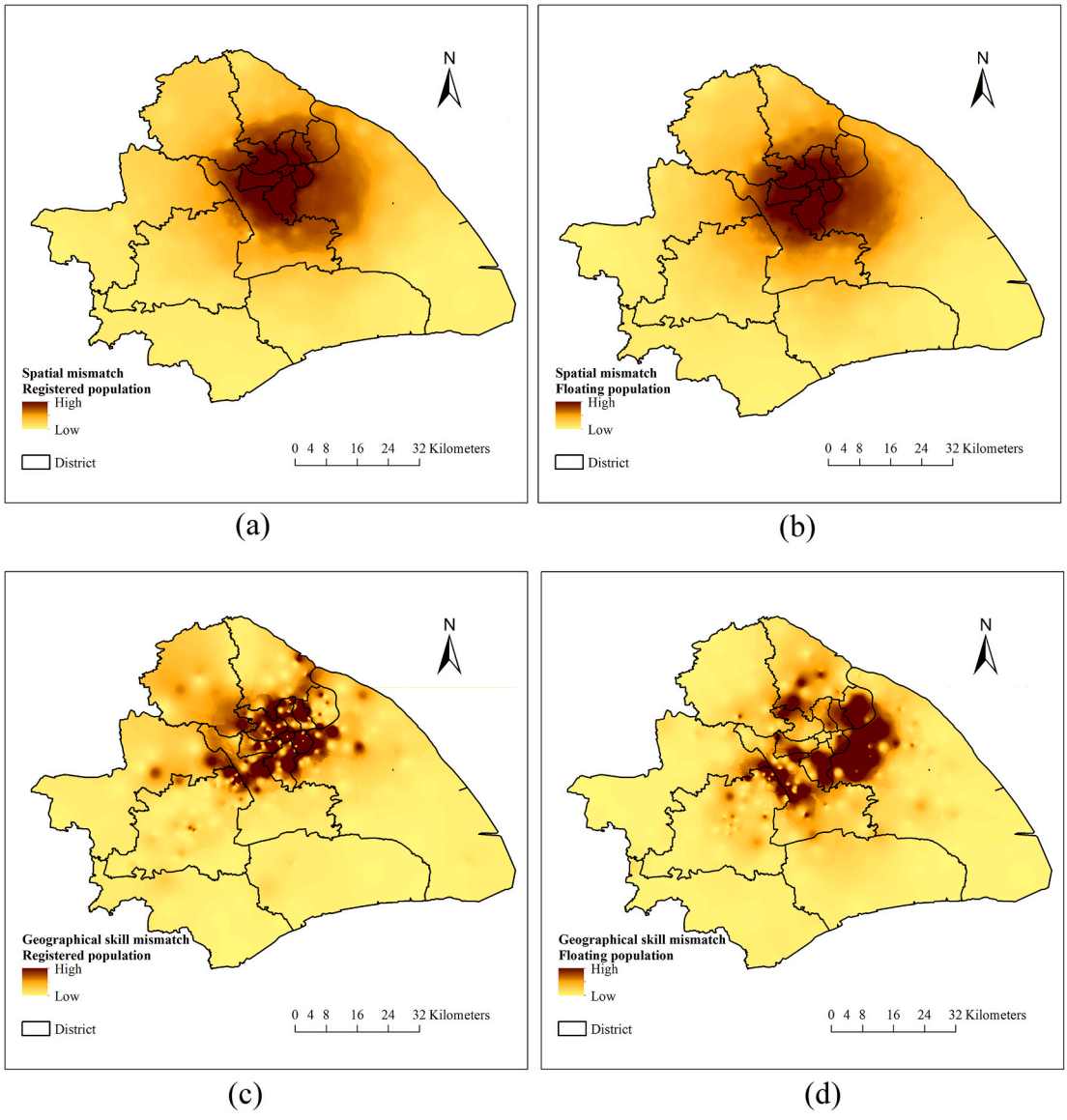

Fig. 4. Job accessibility based on spatial mismatch and based on geographical skill mismatch for registered and floating population.

Since the job opportunities are highly concentrated in the central urban area, the traditional spatial mismatch shows a core-periphery pattern. The central urban areas and suburban areas close to the central urban area have much higher job accessibility than the other suburban areas. Since traditional spatial mismatch does not consider the skill-related factors, including education and salary, there is no significant difference between the floating population and the registered population.

On the other hand, the spatial distributions of geographical skills mismatch for the floating population and registered population show different patterns. The regions with high job accessibility for the registered population are still located in the central urban area except for the districts like Yangpu from the geographical skills mismatch perspective. Furthermore, we can find some low values in the central urban area. It could be explained by the existing urban villages in the central urban areas, where the major residents are low-skill population. For example, we can see a significant difference between spatial mismatch and geographical skills mismatch in the northern part of the Zhabei district, the home of "the last urban village" within the inner-ring of Shanghai. Another example could be found in the western part of the Xuhui district, where a famous urban village named "Zoujiazhai" is located.

The floating population usually has high job accessibility in the Yangpu, Xuhui, and the western part of the Pudong district, growing and having a high gross demotic product (GDP). Particularly, Xuhui and the western part of the Pudong districts serve as China's financial center, undergoing rapid economic growth and urban development. The high-skill jobs attract many well-educated and high-skill floating population to move there for better job opportunities and a higher salary. Also, the housing price in these regions is more affordable than others in the central urban area. Thus, these regions are suitable for the high-skilled floating population, which provides the right living environment and proximity to job opportunities. The traditional expanded central urban areas in the north-eastern part are not attractive to the floating population for lacking high-skill jobs.

5.2. Geographical skills mismatch and residential segregation

The floating population in Shanghai, in particular, the poor migrants, are indicated to be segregated from the registered population and sometimes have poor social integration (Liu et al., 2018). Table 2 also suggests that the high-skill floating and registered populations are segregated in some districts. Since residential segregation is a critical indicator of poor job accessibility according to western literature (Howell-Moroney, 2005), we use the dissimilarity index to measure residential segregation and explore the relationship between job accessibility and residential segregation (Table 3).

Comparing the two job accessibility indices in Table 3 helps better identify the relative advantages of the geographical skills mismatch approach. First, the geographical skills mismatch approach is more sensitive to the economic and social gaps between the floating population and the registered population than the spatial mismatch approach. Second, the geographical skills mismatch approach can reflect a more detailed spatial configuration of job accessibility in Shanghai because it considers more variables. Also, geographical skills mismatch highlights the impacts of urban inequality on job accessibility and would not overestimate job accessibility in the urban villages.

The results also suggest increased residential segregation from the central urban area to the urban periphery in Shanghai. In the traditional central urban area, living space is mostly limited, and the floating population and registered population are less segregated. As the residential segregation increases in the expanded central urban area, the differences between the floating population and the registered population's job accessibility are closing. There is a significant decline in the registered population's job accessibility, while the floating population's job accessibility increases. Thus, residential segregation does not have significant impact on job accessibility in the central urban area. The job opportunity concentrations are likely to create a floating population cluster because they come to Shanghai for jobs.

Residential segregation increases in suburban areas, and both the floating and registered population's job accessibility decreases rapidly. This phenomenon suggests people living in segregated communities would have poor job accessibility, no matter the floating population or the registered population. However, it is still hard for us to conclude that residential segregation influences the floating population's job accessibility. Residential segregation is the outcome of social or cultural reality. Other factors, such as the local housing market and economic development, contribute to residential segregation and influence job accessibility (Li, Campbell, & Fernandez, 2013). Thus, we implement a path analysis to reveal the intertwined relationship between job accessibility, residential segregation, urban structure, local economy, and working skills.

Table 3
Residential segregation and job accessibility index in Shanghai by district.

District	Dissimilarity index	Job accessibility index			
		Geographical skills mismatch		Spatial mismatch	
		Floating population	Registered population	Floating population	Registered population
Traditional city proper area					
Huangpu	0.164	1.141	2.155	3.140	3.189
Jing'an		1.471	3.414	3.409	3.469
Expanded central city area					
Xuhui	0.243	2.001	2.408	3.209	3.210
Changning		1.356	1.977	3.483	3.408
Putuo		1.097	1.772	2.656	3.018
Zhabei		1.377	1.683	3.145	2.633
Hongkou		1.420	2.071	2.520	2.633
Yangpu		1.557	1.293	2.077	2.032
Inner suburban area					
Pudong	0.291				
	0.861	0.925	1.160	1.472	
Minhang		1.395	1.152	1.789	2.013
Baoshan		0.705	0.914	1.263	1.484
Outer suburban area					
Jiading	0.310	0.412	0.390	1.128	0.854
Qingpu		0.168	0.514	0.452	0.611
Songjiang		0.494	0.581	0.944	0.993
Jinshan		0.063	0.060	0.138	0.137
Fengxian		0.093	0.161	0.292	0.307

6. Path analysis: determinants of job accessibility

The path analysis explores the intertwined relationship between job accessibility, residential segregation, sociodemographic status, and amenities. The results of path analysis are presented in Table 4 with two models, separately for spatial mismatch and geographical skills mismatch as measures of job accessibility. Examining the good-fitness measures, we find that geographical skills mismatch performs much better than spatial mismatch as a measure of job accessibility. Geographical skills mismatch could better explain the relationship between job accessibility and the determinants using the current framework.

The coefficients from the model concerning geographical skills mismatch suggest that people's working year is positively associated with job accessibility. The long years of working experience usually mean high working skills, and the model results suggest that people with high skills are likely to have higher job accessibility. Income and education also can represent people's working skills. The path analysis reveals that people with high income and education levels have a significant advantage in access to job opportunities. Thus, the poor migrant workers with low education levels might struggle in Shanghai's current job market, even with urban villages that provide residences close to job opportunities. The working space in Shanghai is not self-contained for poor people, and they have to take long-time commuting. In this survey, there about one-fourth of the total floating population have agriculture *Hukou*. According to the path analysis, people with a floating population are likely to have low income and education, contributing to poor job accessibility. Although the Chinese government has already attempted to cancel the classification between agriculture and nonagricultural *Hukou*, the gaps still exist. Thus, poor job accessibility becomes a barrier to attracting cheap labor forces and influences sustainable urban development.

Residential segregation has been well documented in western literature as a determinant of job accessibility (Kain, 1992). Table 4 suggests that residential segregation contributes to poorer job accessibility in Shanghai. There are several reasons that people are segregated. For example, the well-educated floating population is more likely to be segregated than others. There are several concentrations of the high-skill floating population in the periphery of the central urban area, such as Xuhui, Minghang, and Pudong districts. These regions provide a good living environment and affordable housing for the well-educated floating population—however, limiting job opportunities. There is no concentrated residence for the registered population, and they are more flexible in selecting residences closed to their jobs.

Other than socioeconomic status, the local housing market and the urban structure significantly influence the formation of residential segregation and job accessibility. High housing price decreases residential segregation and is positively associated with job accessibility. The regions with high housing prices are closed to the CBD of Shanghai, and both the floating population and registered population have limited choices of residences. The communities with a good living environment and job accessibility are attractive to both the floating and registered population. Thus, people living in regions with high housing prices are usually mixed with the floating and registered population with good job accessibility.

On the other hand, high rent price would increase residential segregation and contributes to poor job accessibility. High rent price is driven by many other factors other than job accessibility, such as the distance to public transit stations (Li et al., 2019). On the other hand, the registered population would like to live in their homes while the rent price is high. Communities with high rent prices are attractive to the floating population and contribute to residential segregation. Thus, high rent price is not primarily driven by the proximity to the job centers but contributes to residential segregation and decreases job accessibility.

Furthermore, the ring roads in Shanghai shape the urban structure and influence job accessibility. The model results suggest that the regions located close to Shanghai's CBD have a lower residential segregation level because of limited space for living. This phenomenon corresponds to the relationship between housing price and residential segregation, while the housing price in Shanghai shows a gradient from the CBD.

The total effects of the variables on job accessibility are calculated by summing up the direct and indirect effects (Table 5). Although the well-educated floating population is residentially segregated, education's negative impact on the floating population's job accessibility is meager. Thus, education still contributes to better job accessibility for both the floating and registered population. On the other hand, agriculture *Hukou* is a driving determinant of the floating population's job accessibility, and the floating population with agriculture *Hukou* is disadvantaged in the current job market. Comparing other coefficients, the well-paid floating population with high skill would be more popular than others

Table 4
Results of path analysis.

	Coefficients (Geographical skills mismatch)		Coefficients (Spatial mismatch)	
	Registered population	Floating population	Registered population	Floating population
JAI ← Segregation	−0.250***	−0.191***	−0.759***	−0.618***
JAI ← Income	0.067***	0.108***	0.002	0.038***
JAI ← Education	0.414***	0.483***	0.091***	0.139***
JAI ← Working years	0.067***	0.064***	0.033***	0.039***
Income← Agriculture *Hukou*	/	0.285***	/	0.285***
Education ← Agriculture *Hukou*	/	0.616***	/	0.616***
Segregation ← Education	0.005	0.078***	0.005	0.083***
Segregation ← Housing Price	−0.703***	−0.608***	−0.728***	−0.635***
Segregation ← Rent Price	0.117***	0.203***	0.126***	0.233***
Segregation ← Inner ring road	−0.193***	−0.234***	−0.190***	−0.235***
Segregation ← Outer ring road	−0.058***	−0.139***	−0.062***	−0.127***
Good-fitness measures				
Comparative Fit Index (CFI)	0.979	0.916	0.744	0.704
Degree of freedom	6	19	6	19
Chi-square	191.823	1511.73	3748.726	4434.774

Note: *** Significant at 0.01 level.

Table 5
Total effect of the variables on job accessibility.

	Geographical skills mismatch		Spatial mismatch	
	Registered population	Floating population	Registered population	Floating population
Income	0.067***	0.108***	0.002***	0.038***
Education	0.065***	0.052***	0.029***	−0.013
Working years	0.067***	0.064***	0.033***	0.039***
Agriculture Hukou	/	0.359***	/	0.096***
Housing price	0.182***	0.121***	0.533***	0.392***
Rent price	−0.032***	−0.044***	−0.096***	−0.144***
Inner ring road	0.047***	0.045***	0.052***	0.078***
Outer ring road	0.017***	0.024***	0.144***	0.145***

Note: *** Significant at 0.01 level.

in Shanghai's job market.

The comparison between these two models has some implications. First, the high-income registered population's job accessibility is more sensitive to geographical skills mismatch than the traditional spatial mismatch. The high-skill floating population still would like to reside close to job centers for more potential job opportunities. Furthermore, the coefficients of residential segregation in the model for the spatial mismatch are much higher than those for the geographical skills mismatch. Thus, residential segregation primarily increases the physical distance between jobs and population rather than creates skills mismatch. The total effects in Table 5 show that education level becomes an insignificant factor of the floating population's job accessibility measured by the spatial mismatch. Thus the well-educated population has high job accessibility does not because they live close to the job center. They live close to the job market that is suitable for them to improve their job accessibility.

7. Conclusion and discussion

As the urban structure is shifting in urban China, people's commuting time keeps rising, and poor job accessibility becomes an emerging urban problem. Current research has a limitation in capturing job accessibility, while geographical skills mismatch is rarely considered as a critical concern. The differences in job accessibility between the floating and registered population caused by sociodemographic status would be underestimated (Hu et al., 2017). The spatial pattern and underlying mechanism of job accessibility are also unstudied, particularly the intertwined relationship between job accessibility, residential segregation, urban structure, and amenities. This paper develops a quantitative measure of job accessibility using an extended 2SFCA method considering geographical skills mismatch to identify the spatial pattern of floating and registered population's job accessibility. Then, following the existing literature on the causes of poor job accessibility concerning sociodemographic status, residential segregation, and urban amenities (Gobillon et al., 2007; Hu et al., 2017; Kain, 1992), we employ a path analysis to understand the intertwined relationship among these factors.

Existing quantitative measures of job accessibility are usually developed based on the traditional spatial mismatch hypotheses that focus on the physical disconnection between jobs and population (Grengs, 2010; Hu et al., 2017; Kain, 1992). Chinese megacities, especially their inner cities, are embedded with urban village mosaics, which are the enclaves of low-income and low-skilled workers. Traditional spatial mismatch studies assume that they have the highest job accessibilities because of the proximity to urban and job centers. However, these workers cannot meet the job skill requirements in the central urban area, and they still suffer from poor job accessibility. This phenomenon cannot be correctly reflected in the spatial mismatch method. Our job accessibility index is derived from the geographical skills mismatch hypothesis and is developed based on the 2SFCA method to fully consider the supply-demand relationship between jobs and population (Stoll, 2005).

Based on the comparison to the traditional spatial mismatch approach, we find that geographical skills mismatch could better reveal the impacts of economic and social inequality between the floating population and registered population on job accessibility. Geographical skills mismatch also highlights the effects of spatial inequality on job accessibility, such as the economic and social inequality created by the urban villages. Thus, this methodology is suitable for the highly unequal metropolitan region with mixed living and severe residential segregation.

This job accessibility index shows that the registered population's job accessibility follows the core-periphery pattern. The floating population with high job accessibility is highly concentrated in the expanded central urban area's periphery. The most suitable job market for the floating population can be found in newly developed regions such as Xuhui, Yangpu, and the Pudong district. Thus, from job accessibility, the floating and registered population's job market is highly segregated in the expanded central urban area. The segregation of the job markets is expected in the urban process (Hu et al., 2017), and this research calls attention to the uneven distributions of different job markets in future job accessibility research.

There are multiple causes of job accessibility, and this study pays particular attention to working skills, segregation, and the housing market. We employ a dissimilarity index to measure residential segregation between the floating population and the registered population. The research shows that people living the residentially segregated regions tend to have poor job accessibility. The path analysis results also suggest that residential segregation influences job accessibility primarily by contributes to the physical disconnection between people and jobs rather than geographical skills mismatch. As the residential neighborhoods in Shanghai are likely to be more and more segregated (Li & Wu, 2008), people's commuting time would keep rising, particularly for the low-income migrants with poor housing affordability. The path analysis further sheds light on the determinants of residential segregation. The primary cause of residential segregation is the housing market in Shanghai. The extremely high housing price makes people have to be careful in selecting residential sites and even close the housing choice gaps between the registered and floating population. Thus, the regions with high housing prices are less likely to be residentially segregated and have high job accessibility.

On the other hand, apartments with high rent are favored by the floating population because of the proximity to good urban amenities (Li et al., 2019b). However, this phenomenon would enlarge the residential segregation and contributes to poor job accessibility. Although the affordable housing or public rental housing projects might be a solution, these housing projects are located in the outer urban area that is not friendly to the people, particularly the floating population, working in the central urban area (Cai, 2017).

Despite the impacts of residential segregation and the housing market on job accessibility, people's skills represented by income, education, and working experience are still the dominating factors. People with higher skills have higher job accessibility, reflecting that there is no self-contained urban region for the low-skill workers. Although many sub-centers are emerging in Shanghai (Li & Phelps, 2017), these newly generated sub-centers are not multifunctional enough. These urban sub-centers might create low-skill job markets for low-skill workers in the outer urban areas and raise their expenditure on commuting and creating urban problems such as traffic congestion.

Regarding the rising residential segregation between the floating population and registered population (Li & Wu, 2008) and decreasing housing affordability (Li et al., 2019), urban planners in Shanghai should pay more attention to constructing self-contained neighborhoods. The local government should also promote the current polycentric urban development strategy to create self-sustaining urban establishments in the suburbs (Hu et al., 2017). Existing living neighborhoods, particularly for the floating population in the outer urban area, should be better connected with the public transit system, which could significantly improve job accessibility (Xiao, Wei, & Li, 2021; Xiao, Wei, & Wan, 2021). So far, the light rail system, one of the most popular commuting modes in Shanghai, has inadequate coverage in the outer urban area.

Although this paper manifests the impacts of residential segregation and the housing market on geographical skills mismatch, the underlying mechanism has not been fully revealed. For example, urban villages are mentioned as a cause of geographical skills mismatch in Shanghai, and two examples are provided for validation. But how urban villages shape job accessibility in Shanghai remains unanswered. Moreover, the function of urban villages varies across space. Some urban villages in Shanghai have experienced dramatic transformation since the Shanghai Expo. Thus, detailed case studies about informal settlements in Shanghai and their connections with the city's job accessibility are needed.

Similar, development zones also serve as an urban enclave, which influences the housing/rent market (Li et al., 2019; Li et al., 2019b) and contribute to jobs-housing imbalanced (Xiao, Wei, & Li, 2021; Zhou et al., 2017) in various ways. Future studies could zoom into some exemplary development zones and pay particular attention to the impacts of mixed land use and the housing market on job accessibility (Zhou et al., 2017).

Authorship statement

W.X., D.W. and H.L. conceived and designed the study. W.X. collected data, conducted analyses and drafted the manuscript; W.X., D. W. and H.L. revised the paper.

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