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Decade-long changes in spatial mismatch in Beijing, China: Are disadvantaged populations better or worse off?

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Abstract
Although recent studies have extended the U.S.-centered spatial mismatch hypothesis to Chinese cities, few have examined spatial mismatch conditions over time in Chinese Cities. This research responds to the knowledge gap by using longitudinal data to examine changes in the patterns and magnitudes of spatial mismatch between the 2000s and 2010s in Beijing, China. The longitudinal examination uniquely focuses on spatial mismatch between population and transit-accessible jobs, as opposed to spatial mismatch between population and any jobs. Results show that spatial mismatch conditions worsened among all population groups in the past decade in Beijing, China. When comparing across population groups, spatial mismatch worsened to a much higher degree among disadvantaged groups including the migrant population without local *hukou* and the low-educated population without college education. Further analyses show that changes in population distribution were primarily responsible for the worsened spatial mismatch conditions. Changes in job distribution and transit networks had limited impacts. Policy recommendations to mitigate spatial mismatch in Beijing include reconfiguration of transit networks and promotion of affordable housing development in transit- and/or job-rich areas.

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Introduction

The original spatial mismatch hypothesis had highlighted how African Americans in declining inner-city areas increasingly experienced job-housing mismatch and became disadvantaged in the U.S. labor market (Kain, 1968). Over time, researchers have broadened the spatial mismatch literature in at least four dimensions. First, besides African Americans, many other disadvantaged population groups have been examined for spatial mismatch conditions, including immigrants, unskilled workers, the youth, women, low-income population and welfare recipients, and other racial and ethnic minority groups such as Asians and Latinos (Blumenberg, 2004; Fan et al., 2014; Painter et al., 2007; Stoll, 1999). Second, an increasing number of studies have examined the issue of spatial mismatch in cities outside the U.S., including European cities (Fieldhouse, 1999; Musterd and De Winter, 1998), Asian cities (Kawabata and Shen, 2006; Wang et al., 2011), and Australian cities (Dodson, 2005). Third, unlike earlier studies that typically used measures of residential segregation and commute length, recent studies have used more sophisticated spatial mismatch measures such as dissimilarity indices and accessibility measures (Houston, 2005a; Hu, 2015; Martin, 2004). Finally, issues such as transportation and skills disadvantages have been increasingly studied in conjunction with the issue of spatial mismatch (Fan, 2012; Fan et al., 2010; Houston, 2005b; Taylor and Ong, 1995).

In light of the recent expansions in the spatial mismatch literature, we broadly define spatial mismatch as a mismatch for any specific population group between where they live and where their suitable and accessible job opportunities are. By this definition, spatial mismatch is population-specific and is sensitive to the transportation access and skill levels of the specific population under consideration. The definition defies the measurement of spatial mismatch based upon overall jobs-housing mismatch/imbalance, calling for more nuanced measures that capture the varying degrees of job accessibility and skill requirements across population groups. This population-specific definition highlights the importance of examining spatial mismatch conditions among disadvantaged population groups who tend to be much more constrained in housing, transportation, and employment options.

Most non-U.S. spatial mismatch studies to date have used cross-sectional data that are unable to provide information on longitudinal changes or factors underlying the changes. This is especially disconcerting for cities in developing countries such as China where changes in urban spatial structure, infrastructure systems, and social policy have been relentless. For Chinese cities, structural changes in the society may have significantly altered the spatial mismatch conditions of different population groups in different ways. These structural changes include the housing reform that terminated the traditional work-unit housing allocation system, the economic restructuring, the relaxation of *hukou* system, the changes in land development patterns, and transportation changes such as increased traffic congestion and expanded transit systems. Little is known whether and how these structural changes affected the spatial mismatch conditions over time in Chinese cities across different populations groups, especially among disadvantaged population groups.

To address the knowledge gap, we use longitudinal population, employment, and transit network data to examine changes in the patterns and magnitudes of spatial mismatch between the 2000s and 2010s in Beijing, China. Our longitudinal analyses focus on two specific disadvantaged population groups: the migrant population without local *hukou* and the low-educated population without college education. Methodology-wise, the research involves two major innovations. First, this research applies a dissimilarity index that measures the extent of mismatch between transit accessible jobs and residential population. The index, titled Transit Accessibility Based Dissimilarity Index (abbreviated as DTransit thereafter), takes into account that disadvantaged workers are much more transit-dependent, which is a more accurate measure of spatial mismatch conditions experienced by disadvantaged workers than traditional dissimilarity indices that do not consider transit accessibility . Second, to search for the prime movers underlying changes in spatial mismatch conditions, we calculated DTransit under four scenarios, including the before and after scenarios and two hypothesized scenarios, to separate the transit-, population-, and employment-related impacts on changes in spatial mismatch.

Evolution of spatial mismatch in Chinese cities

With more compact spatial structures, more frequent transit services, and fewer racial segregation issues, Chinese cities had been expected to experience only moderate levels of spatial mismatch (Fan et al., 2014). However, dramatic societal changes in the past several decades in China may have exacerbated the extent of spatial mismatch for specific disadvantaged population groups. This section summarizes major policy changes and other societal changes in China that may have changed spatial mismatch conditions in Chinese Cities. Many of the policy and societal changes began in the late 1970s, and the scale of the changes was not extensive until the late 1990s. These changes continuously influenced the changing urban landscape of Beijing during our study period between 2000 and 2010.

Housing reform

Prior to 1978, housing distribution was solely a governmental function in China. Housing was considered as a welfare service instead of a consumable commodity. After 1978 and in the 1980s, pilot housing reform programs were carried out to reorganize housing production and promote sales of public-sector housing to individual families. Following the pilot programs, China's State Council made a major decision in 1998 to entirely terminate the welfare housing allotment system that linked housing distribution with employment (Wang and Murie, 2000; Zhu, 2000). Since then, all new employees have been forced to buy or rent houses from the market. This policy change has contributed to the significant residential construction boom, rapid development in the suburban housing market, and increased housing unaffordability in Chinese cities (Lau and Li, 2006; Zhou et al., 2013). Residential suburbanization and increased housing unaffordability are likely to constrain the housing options of the disadvantaged population groups at the urban fringe, which may exacerbate their spatial mismatch conditions.

Hukou reform

The *hukou* system in China was codified in 1958 as a household registration and residence permit system (Chan, 2009). For decades, the system has imposed significant limits on Chinese citizens seeking to move freely in search for work and/or housing. It has especially constrained the flow of population from rural villages to urban areas. In 1985, the system was loosened to allow rural migrants to temporarily live and work in cities (Zhao and Howden-Chapman, 2010). However, a temporary residence and work status in an urban area does not mean a transfer of the *hukou* registration to the urban area (Chan and Buckingham, 2008). Because many social services in China such as affordable housing provision and educational and health benefits are dependent on possession of a local, urban *hukou*, the incomplete *hukou* reform in 1985 made rural-to-urban migrants second-class citizens in urban areas (Lin et al., 2011; Zhang, 2005).

Since the late 1990s, China has made several policy changes to allow easier transfers of *hukou* registrations to urban areas. These changes include a national relaxation of limitations on migration to small towns and cities, and policies to grant migrants who have a fixed place of residence and a stable income in large cities either permanent residence status or a local urban *hukou* (Wang, 2004). However, eligibility requirements such as stable income sources and fixed residence places exclude the vast majority of Chinese migrants who often work as manual laborers and live in temporary accommodations.

Overall, the *hukou* reform is expected to exacerbate spatial mismatch conditions in two aspects: (1) the reform has created a disadvantaged population group—rural-to-urban migrants who have limited housing options and limited access to social services in urban areas; (2) the reform contributes to the urbanization process that leads to higher demand for urban housing as well as residential suburbanization and urban sprawl (Zhang, 2007; Zhao and Howden-Chapman, 2010).

Economic reforms and restructuring

Economic reforms in China since 1978 have focused on private sector development. The early efforts involved permissions for foreign investments and for entrepreneurs to start businesses. The more recent efforts focused on privatizing state-owned businesses and lifting regulations to allow larger-scale economic growth in the private sector. As of 2015, the private sector accounted for 85% of China's enterprises and 62.5% of employment (National Bureau of Statistics of China, 2016). In addition, China's national policy has promoted rapid development in the service sector due to the higher profit margins for the service sector businesses than the industry and construction sector businesses. Between 2005 and 2015, the industry and construction sector's contribution to the gross domestic product reduced from 47% to 40% and the service sector's contribution increased from 41% to 51% (National Bureau of Statistics of China, 2016).

The rapid growth in the private sector and the service sector changed employment distribution patterns. After the emergence of the urban land market enabled by the 1988 amendment to the Constitution, private-owned and profit-driven enterprises began making location and relocation decisions based upon land values and their profit margin. The bid-rent process boosted the land values in the central areas of Beijing and pushed the industry and construction sector to move towards the urban fringe areas. Yet, businesses in the rapidly growing service sector quickly filled the space left by the industry and construction sector and strengthened the central business districts (Liu et al., 2011; Qiu et al., 2008). The market-oriented relocations decentralized the industry and construction jobs and centralized service jobs (Feng et al., 2008).

China's economic restructuring process has also been characterized by government-arranged relocations of industry jobs. Local governments had arranged relocations of businesses in the industry and construction sector from central areas to fringe areas as early as the 1980s (Feng et al., 2008). These government-initiated relocations focused on environment polluting industries and had the goal of improving environmental conditions in central cities. In addition, satellite towns had been created to reduce the excessive concentration of industries in core urban areas (Yeh and Yuan, 1987; Zhou and Ma, 2000).

In 1983, satellite towns were included in the master plan of Beijing, which encouraged not only businesses in the industry and construction sector but also government agencies, research institutes, and universities to relocate to satellite towns. In the master plan of Beijing in 2004, eleven new towns were planned between the 5th and 6th ring roads to further accept clusters of service- and technology-oriented businesses.

The effects of economic reforms and restructuring on spatial mismatch are unclear. On one hand, privatization and service-sector promotion have decentralized the industry and construction sector. On the other hand, the growing service sector tends to concentrate in city centers, retarding the overall job decentralization trend. Nonetheless, government-arranged relocations and satellite town establishments have created new areas of job concentration that typically do not overlap with areas of residential concentration, causing fragmented land development patterns and spatial separation of jobs and housing (Zhang, 2000; Zhao et al., 2009).

Rapid urbanization and urban land reform

Before the reforms and under the planned economy, the government owned the urban land and designated the utilization of all urban land, prohibiting any leasing or transaction. After reforms began in 1978, China's urbanization accelerated. In 1978, 18% of people in China lived in urban areas. By 2015, the urban population had grown to 56% (National Bureau of Statistics of China, 2016). Following the rapid urbanization, an amendment was made to the Constitution of the People's Republic of China in 1988 to separate land use rights from land ownership (Yuan, 2004). The amendment allowed transferring of land use rights, and legalized leases and transactions of land use rights.

As the urban land reform established the basic legal foundation for the urban land market, an urban land market emerged and changed the spatial relationships between jobs and housing. Specially, rapid urban development continuously pushed the urban land boundary beyond the limits set by the city's master plan. Driven by the high land prices in central cities, old housing in central cities had been increasingly replaced by high-rise office buildings. Central business districts began to emerge in many Chinese cities, attracting various businesses seeking high visibility and in turn enhanced the land price in central cities. Developers of new commercial housing turned their attention to the suburb of the cities, accelerating residential suburbanization and urban sprawl (Deng and Huang, 2004; Feng et al., 2008; Zhang, 2000).

Urban land reform also shifted urban land leasing and management responsibilities from the central government to the local governments. Along this change, local governments inherited the responsibility to fund most of their municipal services using local funding generated by the sales of land use rights (Zhang and Fang, 2004). Consequently, local governments encouraged the most profitable uses of urban land such as luxury apartments and commercial uses, creating shortage of low-end affordable housing. Given their impacts on residential suburbanization and affordable housing shortage, rapid urbanization and urban land reform are likely to exacerbate spatial mismatch conditions for disadvantaged population groups.

Rapid motorization and urban commuting problems

With decades of rapid economic growth, China has experienced a rapid increase in motor vehicle ownership and use. Car ownership rate increased from 0.27 persons per 1000 people in 1985 to 128 person per 1000 people in 2015 (Feng and Li, 2013). Both rapid motorization and urbanization put huge pressure on transportation networks, and the sprawling and fragmented land development patterns further aggravated the problem. Traffic congestion has become a serious problem for many cities in China. For example, the average travel speed on major arteries has plummeted from 45 km/h in 1994 to 12 km/h in 2003 in central Beijing (Cervero, 2004).

The central and local governments in China have supported public transit investments as a way to tackle traffic congestion (Cervero and Day, 2008; Zhang, 2007). In 2004, the Ministry of Construction issued the "Opinions on Priority to Develop Urban Public Transportation" (City Construction No. 38), which was the first initiative at the national level proposing public transportation as a social welfare measure related to national economic progress and livelihood improvement (Wan et al., 2013). The low-price public transit policy was implemented in Beijing in 2007 to promote the use of the public transit system. In 2011, the Ministry of Transport of China initiated the Transit Metropolis Program to foster public transit expansion in 37 pilot cities (Ministry of Transport of the People's Republic of China, 2011). These transit promotion policies were paired with automobile restriction policies. These policies often include restriction of cars that could enter common road space based upon the last digits of the license number on certain established days during certain periods, and/or a lottery system that restricts car purchases.

On one hand, increased traffic congestion has lengthened commuting time and exacerbated the spatial mismatch conditions for all population groups. On the other hand, the increasing investments on public transit and restrictions on private vehicles may reduce the impact of congestion on spatial mismatch conditions and especially mitigate the spatial mismatch problem of people who use transit. The transit priority policies also create a unique context in large Chinese cities that public transit is the primary mode of work commuting. Spatial mismatch indices without consideration of transit accessibility may not be appropriate measures of spatial mismatch in Chinese cities (Fan et al., 2014).

Existing literature on spatial mismatch in China

Studies on spatial mismatch in China began in the mid-2000s. Early studies on the subject were largely conceptual, discussing how ideas and hypotheses in the U.S.-centric spatial mismatch literature may or may not be applied in the contexts of Chinese cities (Li and Wu, 2006; Zhou, 2004). Empirical studies using survey and/or census data to analyze spatial mismatch conditions in Chinese Cities began in the late-2000s. Table 1 summarizes these empirical studies.

From its beginning, equity concerns regarding disadvantaged population groups have been at the forefront of the spatial mismatch literature. Table 1 excludes many studies (e.g. Meng and Fang, 2007; Sun et al., 2008) that examined the overall jobs-housing mismatch issues in Chinese cities and yet did not analyze how mismatch may disproportionally affect disadvantaged populations. Empirical studies in Table 1 provide consistent evidence that disadvantaged groups in Chinese cities suffer from a higher extent of spatial mismatch than their advantaged counterparts. However, disadvantage groups identified in the China spatial mismatch literature are largely different from those identified in the U.S. literature based upon race, ethnicity, immigrant status, and gender. As shown in Table 1, the disadvantaged populations in the China spatial mismatch literature are largely residents in specific housing settlements (e.g. suburban, urban villages, non-Danwei housing, government-subsidized rental housing, and low-income housing), low-skilled and low-educated workers, and/or migrant workers without local *hukou*.

Table 1. List of studies on spatial mismatch in Chinese cities.

Author, year	Study area	Disadvantaged population	Measures of spatial mismatch	Data source	Longitudinal?
Chai et al. (2011)	Beijing	Government-subsidized housing residents	Commute length	Survey	No
Fan et al. (2014)	Beijing	Low-skilled workers; migrant workers	Dissimilarity indices	Census	No
Li and Liu (2016)	Guangzhou	Migrant residents	Commute length	Survey	No
Li et al. (2013)	Wuhan	Government-subsidized housing residents	Commute length	Survey	No
Lin and Gaubatz (2017)	Wenzhou	Migrant residents	Commute length	Survey	No
Liu and Wang (2011)	Beijing	Low-income residents	Commute length and job accessibility index	Survey and census	No
Luo and Zeng (2015)	Chongqing	Government-subsidized housing residents	Commute length	Survey	No
Song et al. (2007)	Beijing	Suburban residents	Commute length	Survey	No
Wang and Chai (2009)	Beijing	Non-Danwei housing residents	Commute length	Survey	No
Wang et al. (2009)	Lanzhou	Urban village residents	Distance to job centers	Survey	No
Wang et al. (2011)	Beijing	Low-income residents	Commute length and dissimilarity index	Survey and census	Yes
Xu et al. (2013)	Shanghai	Displaced low-income residents	Commute length	Census	Yes
Yao (2010)	Beijing	Low-educated, blue-collar workers	Commute length	Survey	No
Zhang and Man (2015)	Beijing	Government-subsidized housing residents	Job accessibility index	Census	Yes
Zhao (2015)	Beijing	Low-income workers	Commute length and jobs-housing ratio	Survey	No
Zhou et al. (2013)	Guangzhou	Government-subsidized housing residents	Commute length and job accessibility index	Survey	Yes
Zhou et al. (2016)	Guangzhou	Low- and middle-income workers	Commute length and dissimilarity index	Survey and census	Yes
Zhu (2016)	Multiple cities	Migrant workers	Urban village residence	Survey	No
Hu et al. (2017)	Beijing	Low-educated population	Job accessibility index	Census	Yes

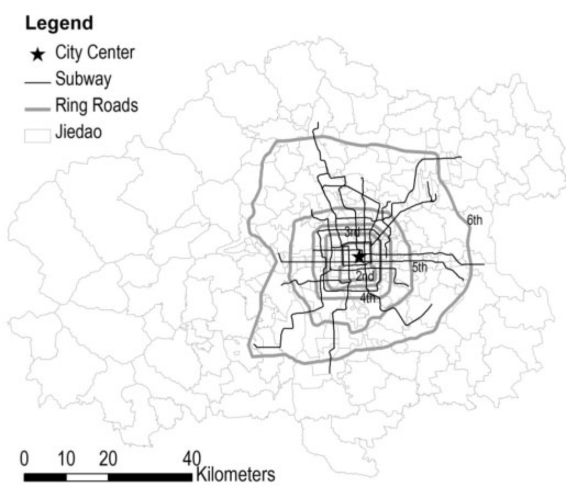
The China spatial mismatch literature is in its early development stage with limited variations in study areas and measurements. Relatively few studies are longitudinal studies. As shown in Table 1, half of the studies (10 out of the 19) on spatial mismatch in China focused on Beijing, the capital city of China. The majority of the studies used simple residence or distance-based measures (e.g. whether living in urban villages or not, distance to job centers, and commuter length) to quantify the extent of spatial mismatch of jobs and housing. Only 7 of the 19 studies used sophisticated measures such as job accessibility and jobs-housing dissimilarity indices. In addition, only 6 of the 19 studies used longitudinal data to provide insights into how spatial mismatch conditions may have changed over time in Chinese cities.

Three of the six longitudinal studies focused on changes in spatial mismatch in Beijing, China (Hu et al., 2017; Wang et al., 2011; Zhang and Man, 2015). Using both Census and survey data, Wang et al. (2011) confirmed that the spatial mismatch conditions in Beijing had become worse between 1990 and 2007. They found that low-income residents were burdened with similar time costs for overcoming spatial mismatch when compared to high-income residents. Zhang and Man (2015) used Census data and calculated the average public transit time from their homes to commercial and industrial job centers before and after 2004 in the wake of the 2004 Beijing Comprehensive Plan. They found that after 2004 travel by public transit from affordable housing sites took nearly double the amount of time as travel by car to the job centers. Hu et al. (2017) utilized census data to examine changes in job accessibility for the low- and high-educated population from 2000 to 2010. They found that the low-educated has lower job accessibility and has moved outward to the suburbs, away from places of high job accessibility. All the three studies provided some evidence that the spatial mismatch problem in Beijing worsened in recent years and that the problem disproportionately affected low-income residents who are transit-dependent. However, none of the studies proposed a comprehensive framework of how and why the spatial mismatch problem may have exacerbated in Chinese cities, nor did they directly quantify the extent of spatial mismatch for specific population groups.

Study area and data source

Beijing, the capital of China and the second largest Chinese city in population size, is selected as the study area. Although Beijing is admittedly unique in its scale and political status, we expect that Beijing could be representative of other large Chinese cities in a number of ways, including the kind of planning and land reform practices used, the kind of socio-spatial polarization observed, and the kind of changes in industrial layout and residential distribution experienced (Deng and Huang, 2004; Gu and Shen, 2003).

Figure 1 shows the boundaries of the 246 *jiedaos* (subdistricts) in the Beijing metropolitan area in 2013. *Jiedao* has been the basic administrative spatial unit in Chinese cities for decades and is the lowest geographic level reported in publicly accessible government statistical reports (Gu et al., 2005). Figure 1 also shows the location of the Forbidden City (i.e. the old city center), the five most important ring roads from the 2nd to the 6th Ring Roads, and the subway network as of 2015 in Beijing.



Study Area Characterisitcs

Area unit: Jiedao

# of area units: 246

Area size: 9,116 sqkms

Item	2000	2010	Annual Growth Rate
Population (million)	12.13	18.01	4.03%
population density (Persons/Sqkm)	1331.03	1975.04	4.03%
Population aged 6 & older (million)	11.67	17.28	4.00%
	2004	**2013**	
Total Jobs (million)	6.63	10.01	4.68%

Figure 1. Study area map and characteristics.

Jiedao-level jobs data come from the 2004 and 2013 Economic Census; and *jiedao*-level residential population data come from the 2000 and 2010 Population Census. Population Census defines residential population as residents who lived in the *jiedao* for more than six months at the time of the survey, regardless of their *hukou* status. Note that *jiedao* boundaries change over years. To make spatial analysis results easier to compare across years, we adjusted the population and employment data of each data year to in accordance with the 2013 *jiedao* boundaries.

Because public transit is the primary mode of work commute in Beijing (50% of the commuting trips use public transit and 31.9% of them using private cars) and disadvantaged population groups tend to be transit-dependent (Beijing Transportation Research Center, 2016), our analyses examine spatial mismatch between population and transit accessible jobs, as opposed to spatial mismatch between population and any jobs. Such analyses require longitudinal data on the transit network in Beijing, China. We only had access to weekday, morning-peak transit network data in 2005 and 2015. The 2005 network was developed using historic data on transit stops, routes, and schedules, and the 2015 network was obtained from the Baidu Direction API. Baidu is a web service company that offers mapping solutions in China.

In this paper, the 2005 transit network data were paired with the 2004 jobs data to calculate transit accessible jobs available to the 2000 population, which constructs the before scenario. The 2015 transit network data were paired with the 2013 jobs and the 2010 population to construct the after scenario. The discrepancy between data years admittedly affects comparability. Nonetheless, our comparison used the best data available and provided important insights into longitudinal changes in spatial mismatch conditions between the early 2000s and the early 2010s in Beijing, China.

Analysis and findings

Identifying disadvantaged population groups and low-skilled jobs

Our longitudinal analysis focuses on two disadvantaged population groups: one is migrant population without local *hukou* and the other is low-educated population without college education. As mentioned earlier, migrant population without local *hukou* is socio-economically disadvantaged because China's social welfare provision is tied to the local jurisdictions where people officially registered their *hukou*. Besides *hukou*, we use education to indicate socio-economic status. Education is used as opposed to income because China's Population Census does not provide income data at the *jiedao* level.

When examining spatial mismatch for low-educated population, it is more appropriate to match them with low-skilled jobs that have low educational requirements. The 2004 and 2013 Economic Census do not provide *jiedao*-level employment data by education but by sector. This allows us to classify low-skilled jobs based upon sector-level information. To do so, we calculate the percentage of workers with college education for each of the 18 sectors listed in Table 2. If a sector has a lower percentage of high-educated workforce than that of the whole workforce (i.e. the percentage of total workers with college education in Beijing, China, which is 39% in 2004), all jobs in this sector are classified as low-skilled jobs without college education requirement. We acknowledge that this sector-based approach ignores the variation in workers' education attainment within the same sector.

The Wholesale and Retail Trades sector is classified as a low-skilled sector although the sector has a slightly higher percentage of workers with college education (40.58%) than the

Table 2. Classification of low- vs. high-skilled sectors using 2004 data.

Sectors	% of workers with college education	High-skilled sectors	Low-skilled sectors
1. Mining	6.06		√
2. Manufacturing	21.99		√
3. Construction	21.09		√
4. Production and distribution of electricity, gas and water	34.85		√
5. Traffic, transport, storage and post	17.28		√
6. Information transmission, computer services and software	84.62	√	
7. Wholesale and retail trades	40.58		√
8. Hotels and catering services	12.95		√
9. Financial intermediation	70.26	√	
10. Real estate	35.15		√
11. Leasing and business services	46.71	√	
12. Scientific research, technical service and geologic prospecting	70.76	√	
13. Management of water conservancy, environment and public facilities	21.19		√
14. Services to households and other services	21.74		√
15. Education	72.32	√	
16. Health, social security and social welfare	51.36	√	
17. Culture, sports and entertainment	62.62	√	
18. Public management and social organization	62.68	√	

Note: The classification standards between 2004 and 2013 have little differences. The classification results of defining low- and high-skilled sectors are the same regardless of whether the 2004 or 2013 standards are used.

percentage of workers with college education in the whole workforce (39%). This decision was made for two reasons: (1) Jobs in the Wholesale and Retail Trades sector tend to be seasonable and workers tend to over-qualify. Although a significant number of people with college education work in the sector, it does not necessarily mean a significant number of jobs in this sector require college education. (2) Classifying the Wholesale and Retail Trades sector as a low-skilled sector helps to make the final percentage of jobs in the identified low-skilled sectors (64% in 2004) closer to the actual percentage of jobs with workers without college education (61% in 2004).

Examine the geography of spatial mismatch

This research goes beyond the conventional comparison between job and population distributions by calculating transit accessible jobs at the *jiedao* level and compares the distribution of transit accessible jobs with population distribution. The number of transit accessible jobs within 60 min of transit travel from each *jiedao* is calculated using the cumulative opportunity approach. We use the 60-minute threshold because the average one-way commuting time by transit in Beijing was 60.5 min for buses and

62.3 min for rail transit (Beijing Transportation Research Center, 2016). The accessibility formula is below:

$$a_i = \sum_{j=1}^{n} e_j f(t_{ij}) \tag{1}$$

$$f(t_{ij}) = \begin{cases} 1; & \text{if} \quad t_{ij} \leq 60\,\text{mins} \\ 0; & \text{if} \quad t_{ij} > 60\,\text{mins} \end{cases} \tag{2}$$

where a_i represents the composite counts of jobs accessible within 60 minutes of transit travel from jiedao *i*. e_j represents the amount of employment in *jiedao j*. As illustrated in equation (1), whether jobs are considered as accessible is dependent upon based upon a travel time threshold function $f(t_{ij})$. t_{ij} represents the travel time by transit between the centroid of jiedao *i* and the centroid of jiedao *j*.

Figures 2 and 3 illustrate the distribution patterns of migrant and local populations in relation to jobs and transit accessible jobs. Figure 2 shows the patterns in a map format and Figure 3 summarizes the patterns by distance to the city center in a bar/line chart format.

As shown in Figure 2, the local population in 2000 concentrated in areas west of the city center and not far away from the city center—largely between the 2nd and 4th ring roads. The migrant population in 2000 concentrated mainly in areas west and south of the city center, but relatively farther away from the city center—largely between the 3rd and 5th ring roads. The concentration areas of both local and migrant population shifted away from the city center and expanded to the north side between 2000 and 2010, and the migrant population experienced additional outward expansion to the east and south sides during the decade. Compared to population, concentrations of jobs and transit accessible jobs are closer to the city center. Between 2000 and 2010, although both concentrations of jobs and transit accessible jobs were increasingly seen in areas between the 4th and 5th ring roads, their concentrations near the city center within the 4th ring road remained strong.

As shown in Figure 3, the percentage of transit accessible jobs near the city center shows a notable increase between 2004 and 2013, while the percentage of local as well as migrant population near the city center decreased. Migrant population has a much higher concentration in areas about 16 kilometers from the city center (i.e. areas between the 4th and 5th ring roads) than local population. It is evident from both Figures 2 and 3 that there were jobs-housing mismatch among local and migrant population in years 2000 and 2010. The mismatch is more evident among migrant than local population, and is more evident in year 2010 than 2000.

Figures 4 and 5 illustrate the distribution patterns of low- and high-educated population (respectively population without and with college education) in relation to overall and transit accessible low- and high-skilled jobs. The residential segregation between low- and high-educated populations is evident in Figure 4. In 2000, low-educated population tended to locate in southwest areas, while high-educated population tended to locate in northwest areas (areas closer to both low- and high-skilled jobs and transit accessible jobs). Between 2000 and 2010, areas with high concentration of low-educated population expanded to north, west and south, while areas with high concentration of high-educated population expanded to north and southeast. After these changes, high-educated population was still

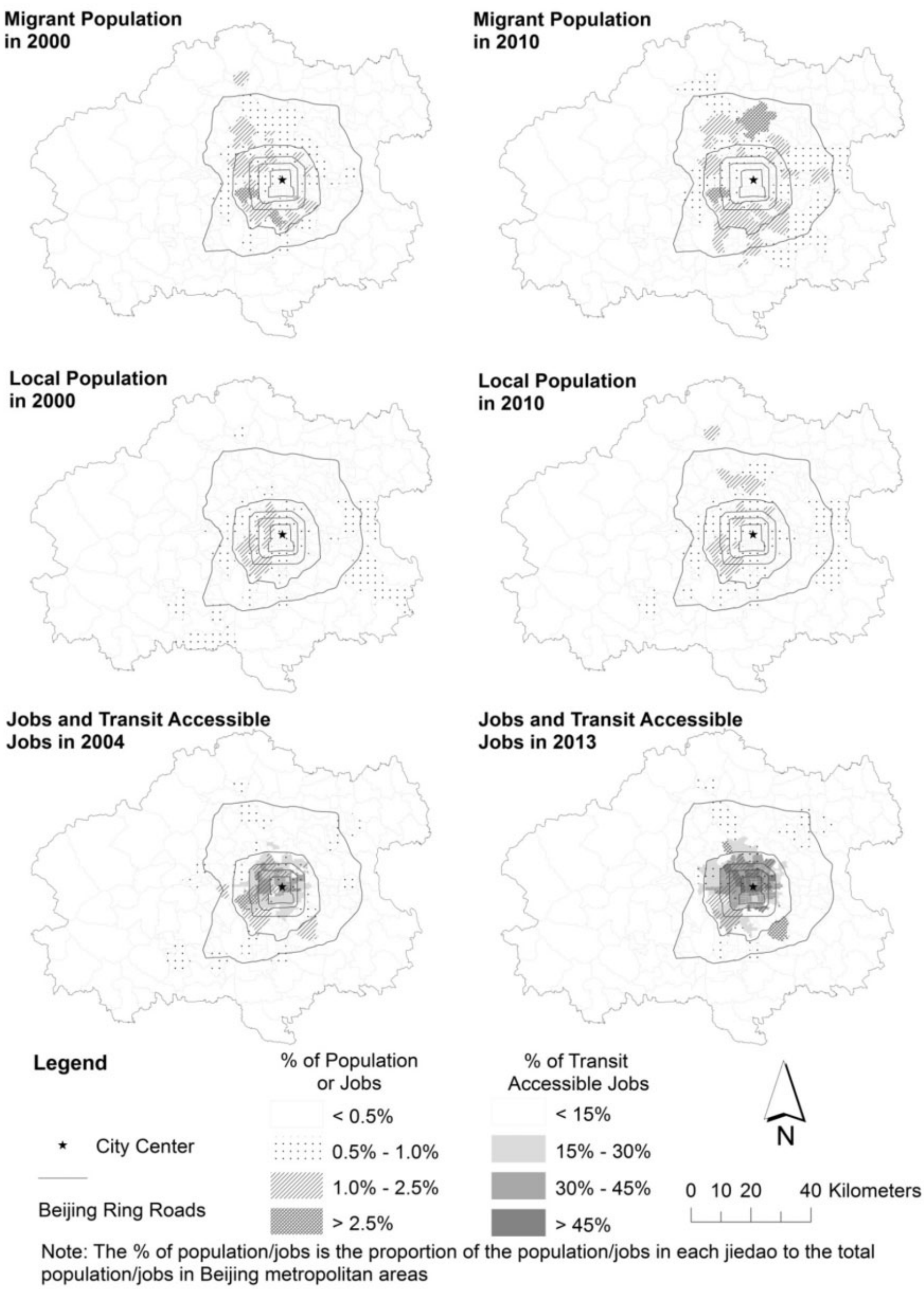


Figure 2. Spatial distributions of population, jobs, and transit accessible jobs.

closer to low- and high-skilled jobs and transit accessible jobs than low-educated population in 2010.

When comparing job distributions with population distributions, jobs (both high- or low-skilled) were located in closer proximity to the city center. Low-skilled jobs were more

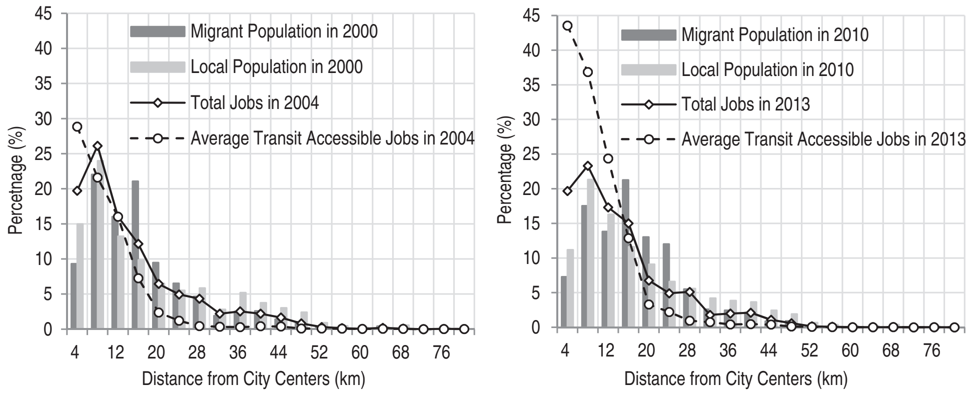


Figure 3. Percentage distributions of population, jobs, and transit accessible jobs by distance to the city center in Beijing.
Note: Using the 4-km intervals are more in line with ring road intervals. In addition, the figure is very sensitive to 1-km difference at locations near the city center. Thus, the 4-km intervals are chosen instead of the more commonly used 5-km intervals. The 4-km intervals are also applied to Figure 5.

spatially dispersed than high-skilled jobs. After taking transit accessibility into consideration, the dispersion of transit accessible low-skilled jobs is rather limited. As the Beijing transit network functions to best serve the city center, transit accessible jobs (regardless of low-skilled or high-skilled ones) remain highly concentrated in areas near the city center. Consequently, spatial mismatch is higher among low-educated population than high-educated population, and the mismatch worsened between 2000 and 2010. These patterns are also evident in the distance charts in Figure 5.

Quantifying the magnitude of spatial mismatch

We quantify the magnitude of spatial mismatch using the dissimilarity index based upon job access by transit (referred as DTransit). First proposed in Fan et al. (2014), the specification of the DTransit index is below:

$$\text{DTransit} = \frac{1}{2} \times \sum_{i=1}^{n} \left| \frac{p_i}{\sum_{i=1}^{n} p_i} - \frac{ca_i}{\sum_{i=1}^{n} ca_i} \right|$$

$$ca_i = \sum_{j=1}^{n} e_j f(t_{ij})$$

$$f(t_{ij}) = \begin{cases} 1; & \text{if} \quad t_{ij} \leq 60\,\text{min} \\ 0; & \text{if} \quad t_{ij} > 60\,\text{min} \end{cases}$$

where p_i and e_i represent respectively the number of population and the number of jobs located in the areal unit i of the study region; ca_i represents the composite counts of jobs

Figure 4. Spatial distributions of low-/high-educated population, low-/high-skilled jobs, and transit accessible low-/high-skilled jobs.

accessible within 60 min of transit travel from areal unit i; t_{ij} represents the travel time by transit between the centroid of areal unit i and the centroid of areal unit j.

The DTransit index measures the magnitude of spatial mismatch between population and transit-accessible jobs, as opposed to between population and any jobs. It has several advantages for measuring spatial mismatch conditions in the context of Chinese cities than traditional dissimilarity indices (Fan et al., 2014). Traditional dissimilarity indices

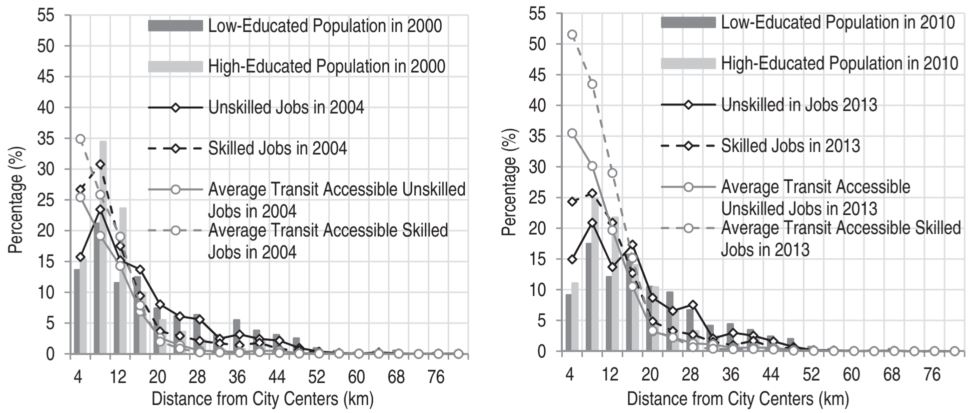


Figure 5. Percentage distributions of low-/high-educated population, low-/high-skilled jobs, and transit accessible low-/high-skilled jobs by distance to the city center in Beijing.

Table 3. Values of the DTransit dissimilarity index over time and across population groups.

	DTransit		
	2000	2010	% Change
Migrant population	0.496	0.588	18.4%
Local population	0.417	0.466	11.8%
Low-educated population	0.449	0.553	23.1%
High-educated population	0.356	0.435	22.2%

often assume that spatial interactions are independent of distance (population can only access jobs in the same areal unit, not even the bordering areal units) or that spatial interactions decrease in a continuous fashion as distance increases. These assumptions are problematic for measuring spatial mismatch in Chinese cities because the primary transportation mode for work commute is public transit and disadvantaged population groups in Chinese cities are especially transit-dependent.

We calculated values of the DTransit index over time and across population groups. Note that for local and migrant population groups, the total jobs data are used; and for the low- and high-educated population groups, the low-skilled and the high-skilled jobs data are respectively used. The results are shown in Table 3.

Table 3 shows that spatial mismatch conditions of all population groups worsened between 2000 and 2010. When compared across population groups, spatial mismatch worsened to a higher degree among disadvantaged groups (18.4% for migrant population compared to 11.8% for local population; and 23.1% for low-educated population compared to 22.2% for high-educated population). In addition, disadvantaged population groups have higher DTransit values than their advantaged counterparts in both year 2000 and 2010. In other words, disadvantaged population groups had suffered higher levels of spatial mismatch in 2000 and their conditions got even worse in 2010.

As of now, we have calculated DTransit under two scenarios, including the before scenario ($DTransit_{before}$) using the 2000 population, 2004 employment, and 2005 transit network data; and the after scenario ($DTransit_{after}$) using the 2010 population, 2013 employment, and 2015 transit network data. The before–after change in DTransit came from three sources including changes in population distribution, changes in employment distribution, and changes in the transit network. To decompose the before–after change in DTransit (i.e. $\Delta DTransit$, which is equal to $DTransit_{after} - DTransit_{before}$) into changes due to population, employment and transit network changes, we construct two hypothetical scenarios (HS):

- HS1: pairing the 2000 population and 2004 employment with the 2015 transit network; and
- HS2: pairing the 2000 population with the 2013 employment and 2015 transit network.

We calculate the DTransit index values under the HS1 and HS2 scenarios, resulting $DTransit_{HS1}$ and $DTransit_{HS2}$. The following formulas are used to decompose the before and after change in DTransit:

- $\Delta DTransit_{transit\ change} = DTransit_{HS1} - DTransit_{before}$
- $\Delta DTransit_{job\ change} = DTransit_{HS2} - DTransit_{HS1}$
- $\Delta DTransit_{population\ change} = DTransit_{afeter} - DTransit_{HS2}$

In the end,

$$\Delta DTransit = \Delta DTransit_{transit\ change} + \Delta DTransit_{job\ change} + DTransit_{population\ change}$$

The decomposition approach is developed based upon Wang et al. (2011). We calculate changes in DTransit due to transit network changes ($\Delta DTransit_{transit\ change}$) first, and then use transit network changes as a precondition to calculate changes in DTransit due to job distribution changes ($\Delta DTransit_{job\ change}$), and finally use both transit network and job distribution changes as a precondition to calculate changes in DTransit due to residential distribution changes ($\Delta DTransit_{population\ change}$). The calculation results are shown in Figure 6.

Figure 6 provides a clear view of the total and decomposed changes in DTransit: all population groups suffered worsening spatial mismatch conditions in the past decade and

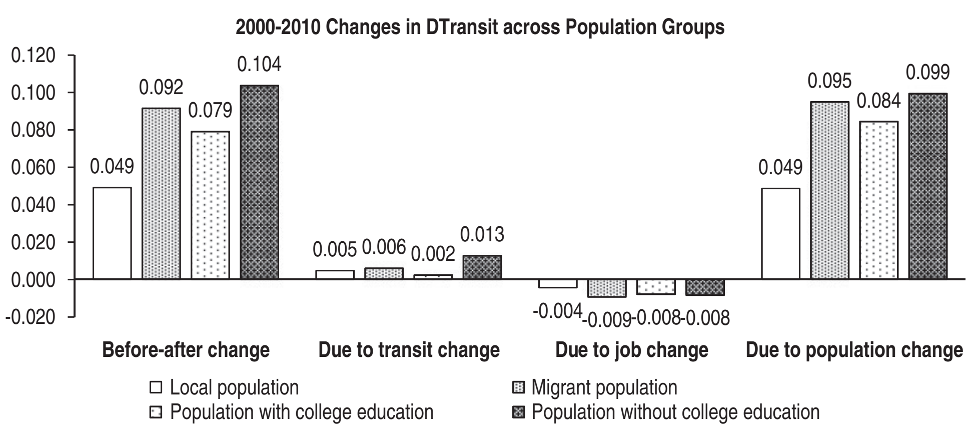


Figure 6. Total and decomposed changes in DTransit across population groups in the past decade.

disadvantaged population groups were worse off compared to their advantaged counterparts. The overall change of the local population is the most moderate, followed in order by high-educated population, migrant population, and low-educated population. The decomposed changes indicate that changes in population distribution (the suburbanization and decentralization trends illustrated in Figures 2 and 4) were the primary driver of the worsening spatial mismatch conditions across all population groups. The impacts of changes in job distribution and the transit network are both modest. Changes in the transit network aggravated spatial mismatch modestly and changes in job distribution mitigated spatial mismatch modestly.

Conclusions and discussion

Waves of policy reforms, rapid urbanization, and associated societal changes in China may have forever changed the spatial mismatch conditions in Chinese cities. This paper develops a theoretical framework detailing how spatial mismatch in Chinese cities may have been exacerbated by at least five factors: housing reform, *hukou* reform, economic reforms and restructuring, rapid urbanization in relation to urban land reform, and rapid motorization in relation to worsening urban commuting problems. Longitudinal data from Beijing, China further confirm that, between 2000 and 2010, spatial mismatch conditions of all population groups worsened. When comparing across population groups, spatial mismatch worsened to a much higher degree among migrant population without local *hukou* than local population, and among low-educated population without college education than high-educated population.

The trend of growing spatial mismatch among disadvantaged populations is not surprising when placed in the broader urbanism literature—urban processes such as labor market segmentation, housing filtering, and social reproduction of class relations tend to reinforce geographic disparities and segregation (Fan, 2010; Wyly, 1999). Nonetheless, the trend is alarming and calls for expanded studies to examine the trend of spatial mismatch across Chinese cities and immediate policy interventions to address spatial mismatch in Beijing, the capital city of China.

Findings from the scenario analyses show that worsening spatial mismatch is more attributable to changes in population distribution than changes in job distribution or changes in the transit network. Specifically, between 2000 and 2010, Beijing experienced rapid population decentralization to areas farther away from the city center while jobs and especially transit accessible jobs remained in areas near the city center. This jobs-housing separation pattern is much more evident in disadvantaged groups than their advantaged counterparts, causing disadvantaged groups to be worse off in terms of spatial mismatch. These findings point to the fundamental challenges to provide affordable housing and to integrate disadvantaged populations into the economy in Chinese cities: city governments need to secure land for development not only at the right price but also at the right locations to connect disadvantaged households to economic opportunities. It may take decades to spatially re-orient disadvantaged communities towards where economic opportunities concentrate. A more urgent need is to reconfigure transit services in Beijing so that transit services do not aggravate but mitigate the worsening spatial mismatch faced by disadvantaged populations.

Finally, spatial mismatch is a complex problem attributable to land use, housing, transportation, and economic development factors. Integrated, cross-sectoral policy solutions that respond to the inter-connectedness between various underlying factors would be more effective than traditional, single-sector policy solutions (Fan, 2012). A marriage between transit development, economic development, and affordable housing provision efforts (i.e. promoting affordable housing development in transit-rich and/or job-rich areas) may present exciting opportunities for addressing the growing spatial mismatch problem in Chinese cities.

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