Amenity Accessibility Evaluation of Shared-Ownership Housing in Beijing

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Abstract

Beijing Housing Authority released a new affordable housing project called "Shared-Ownership Housing" (SOH) in April 2017 to meet the excessive housing demand. However, it has not been welcomed as expected and faced criticism on amenity accessibility. The study used the Spatial Access Model developed by Center of Spatial Data Science at the University of Chicago, to evaluate and compare access to schools, hospitals subway stations and air quality of Shared-Ownership Housing and commercial residential locations. The study found no significant evidence that Beijing Housing Authority had discriminatory site selection process when zoning for SOH. But compared to the more evenly distributed commercial residential locations, SOH locations are all far from the city center and are mostly located in neighborhoods with low access scores.

Keywords: Affordable housing, Shared-Ownership, spatial access model, amenity accessibility

Introduction

In 2017, the Beijing Housing Authority announced a new affordable housing project called "Shared-Ownership Housing" to house low-income families in a growing wait-list (BCHUD, 2017). "Shared-Ownership Housing" (SOH) has allowed affordable housing applicants to purchase their homes in a considerable discount while still having the full right of use by sharing property rights with the city government. The discount could be as high as 50% compared with the fair market value of the property. Applicants who purchase the property can enjoy equal rights in household registration and educational resources in the district as other homeowners.

SOH has several restrictions on purchase and reselling (BCHUD, 2017). First, eligible applicants should not have possessed any residential property in Beijing prior to their SOH purchase. Second, the apartment size is limited to under 90-square meters. Third, purchase prices of the properties should be lower than the average fair market value of nearby commercial residential housing properties (CRH). Fourth, properties in the Shared-Ownership Housing program can't be sold within five years of the purchase. After five years of the purchase, SOH owners can only sell the properties to Beijing Housing Authority or other applicants of the program. The restrictions are designed by the city government to differentiate SOH properties from commercial residential housing properties, which ensures units in the SOH program are "built for to be lived in, not for investment."[1]

Affordable housing in Beijing has long been undersupplied over the period of escalating home prices resulting from the commercialization and privatization of the public housing provision system in 1998 (Garriga et al., 2016). However, it was reported in the news recently that Shared-Ownership Housing has not been as popular as expected and SOH programs encountered low purchase rates at the beginning of sales. For example, 70% of families withdrew from the application process of the first SOH program in Haidian District.[2] From October 2018 to April 2019, the average abandonment rate[3] on the first day of sale in four SOH programs reached 85% among applicants.[4]

A plausible explanation for the negative response from affordable housing applicants is that discriminatory location choices from the Beijing Housing Authority for SOH programs failed to provide necessary amenities including schools, hospitals and transportation. Applicants consist mostly of young working-class families in their 30s with one or two children as well as elderly residents from the inner city (Wang & Murie, 2011). They are sensitive to the above amenities because 1) access to public schools are highly competitive and owners of SOH properties are eligible for local public schools in the same district under the current regulations (BCHUD, 2017), 2) elderly from the inner city require short distances to medical facilities for instant care and emergency services and 3) most working-class families don't have private cars

[1] The 13th National People's Congress of the People's Republic of China. (2018). *Report on the Work of the Government*. Retrieved from http://language.chinadaily.com.cn/a/201903/18/WS5c8efa3da3106c65c34ef20c.html

[2] Yi, C. (2018, March 3). Abandon Rate Reaches 70% of Shared-Ownership Housing. *NetEase News*, Retrieved from http://news.163.com/18/0303/14/DBVTQ9MO0001899N.html

[3] The ratio of applicants in the program waitlist choose not to purchase when properties become available.

[4] Jiafei, W. (2019, April 22). Embarrassment of Shared-Ownership Housing. *National Business Daily*, Retrieved from http://www.nbd.com.cn/articles/2019-04-22/1323915.html

and heavily rely on public transport. However, the pattern of existing SOH program locations shows the scarcity of schools, hospitals and transportation.

This study intends to quantitatively evaluate the amenity accessibilities of Shared-Ownership Housing and examine whether there is discriminatory site selection from Beijing Housing Authority for the new affordable housing programs.

Literature Review

This article aims to contribute to a growing literature on Beijing's affordable housing policy by providing empirical evidence on the discriminatory site selection mechanism that undermined the sustainability of affordable housing program.

Beijing has a 20-year history of affordable housing policies which were born with the marketization of housing market. The Beijing public housing system transformed to a commercialized and privatized real estate market in 1998. This reform unleashed huge demand for properties from rapid urbanization combining with inflows of investment. Home prices has been escalating since 1999 with an annual growth rate of 11.5%.[5] Expensive properties relative to the stagnating income per capita worsen the housing affordability in Beijing (Yang & Wang, 2011).

The Beijing municipal government published its first affordable housing policy, Economical and Comfortable Housing Program (ECH) in 1999. For ECH, land could be allocated to developers with a fee deduction, with the goal of investment profits for real estate developers being limited to less than three percent. The national scheme of ECH also imposed limits on the size of affordable housing units, the design standards of estates and qualifying criteria for potential buyers (State Council, 1998). The project provided 88 housing programs to house than 300,000 families from 1999 to 2009. But it soon faced criticism for its spatial arrangements by choosing locations faraway from downtown and lack of transportation or enough access to public services (Chai, Zhang & Liu, 2011).

The unsatisfying amenity accessibilities of ECH might be rooted in the fiscal structure of municipalities. Scholars such as Lin and Yi (2013) observed that the reformulation of central-local fiscal relations between the central state and local governments in 1994[6] incentivized municipal governments to pursue land development as an important means of revenue generation. Dang et al. (2014) further argued that the lack of amenities from discriminatory site selection is a deliberate local implementation of municipalities, who strive to balance the top-down political pressure with the local fiscal interests, to provide better locations to commercial residential programs for higher profits.

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[5] National Bureau of Statistics of China. *Beijing Commercial Residential Property Prices from 1999 to 2017*. Retrieved from http://data.stats.gov.cn/easyquery.htm?cn=E0105_

[6] The central-local fiscal relation reform that requires municipalities like Beijing accounted for 70% of total public expenditure while collecting less than 50% of total government revenue. However, profits from land development are not included in the revenue shared with the central government.

The current Shared-Ownership Housing program, the second major affordable housing policy after Economical and Comfortable Housing Program, is very likely to persist with the local fiscal interests that incentive municipalities for discriminatory site selection. First, under the SOH scheme, the city loses up to 50% of the land transfer revenue by subsidizing the real estate developers to lower the property prices (BCHUD, 2017). Second, the partial ownerships of SOH properties that belongs to Beijing Housing Authority are difficult to liquidize in the short term. Land zoned as SOH therefore are much less profitable for the city than those zoned as commercial residential properties.

Different models have been used to evaluate the accessibilities to education, medical services and transportation in Beijing. Sun et al. (2017) used the minimum distance[7] model to calculate location attributes of access to hospitals and schools for residential complexes. Dang et al. (2014) used the container model to evaluate transit accessibility by calculating the number of subway stations within 3 km from the center of a neighborhood, while Wang et al (2007) used a minimum distance[8] model for high schools, green space and subway stations. There is no consensus on which model best describes accessibilities for residential complexes in the past literature.

The goal of the study is to quantitatively evaluate the amenity accessibility of Shared-Ownership Housing by creating an indicator framework including education, medical resources, transit access, and air quality of all residential land locations auctioned after 2017. With information on accessibility, this study wants to answer whether there are significant differences in amenity access between Shared-Ownership Housing and commercial residential property locations.

[7] Direct distance

[8] Direct distance

Methodology

The study is object-based. The objects are locations of SOH and commercial residential properties. For each location, we calculate its accesses to transit access, education resources and medical services and simulates its air quality condition (annual PM2.5 level in 2017) using NASA MODIS AOD satellite imagery data.

Spatial Access Model

The method used in this study to evaluate education, medical resources and transit access is Travel-Time Matrix and Access Score (Spatial Access Model) developed by Center for Spatial Data Science at the University of Chicago (Noel, 2019). The Spatial Access Model is an offline, open-source and scalable framework that efficiently measures accessibility.

The first part of the model, Travel-Time Matrix, can calculate the shortest path in time or distance for different transit types (walking, driving). Its core algorithm is the point to point shortest path algorithm (P2P) which generate asymmetric matrices of shortest paths from origin to destination. The P2P algorithm uses OpenStreetMap (OSM) structure (projected in WGS 84) for network distance calculation. The OpenStreetMap structure consists of four basic elements: nodes (latitude and longitude coordinates), ways (streets), relations and tags (metadata of map objects).

P2P locates nearest node in the OSM network for each origin and destination using a k-d tree and then find the Vincenty distance between the two points. The algorithm then converts values in the matrix from distance to travel-time by walking or driving. The default speed for walking is 5km/h and 40 km/h for driving. Certain types of roads like highways are excluded from walking, which may result in null values (recorded as -1) in the walking travel-time matrix.

The second part of the model is the Access Score model. Access Score represents the proximity to different amenities. The model considers location coordinates as the origin and the amenities as the destination. For each origin, the model creates a user-defined buffer based on the travel-time matrix from P2P and generates the score only with the facilities inside the buffer.

Access Score requires users to create a dictionary to assign weights for different categories of facilities and set the number of nearest facilities for each category to be counted in the score. If there is an eleventh hospital within a 30-minute buffer of an origin, the score will neglect it since there are only 10 weights specified under 'Hospitals'. The score is then adjusted by a distance decay function to describe the decreasing speed of a value as the travel-time increases. So, closer destinations will be weighed higher that farther away destinations.

The study did not generate a pooled score to incorporate access scores across amenities since weights defined for amenities are not consistent.

Two-Step Analysis
Accessibility evaluation will be conducted as a 2-step process. First, we use Spatial Access Model on the neighborhood-level to calculate access score for every administrative neighborhood in Beijing. Second, access score or access time (travel time to the nearest destination) will be calculated directly using the residential land locations.

The study will have a comprehensive picture of accessibility for the entire city from the neighborhood-level analysis. We can observe the accessibilities of the neighborhoods that host either Shared-Ownership Housing or commercial residential properties. The first step is necessary also because the public tends to perceive the amenity environment in the macro-level like neighborhood or district. The perception of the surrounding neighborhood of a residential land location plays a vital role in affordable housing applicants' purchase decision.

Data

The facilities information is derived from the "Point of Interest of China" data in 2014 (10.6 million points) shared in the format of an ESRI ArcGIS File Geodatabase[9].

1) School (Education Resources)
6188 observations in total. Categories of school include: universities, high schools, primary schools, kindergarten and occupational schools. The buyers of SOH properties are eligible to enroll their children in public schools at the same district.

Data dictionary used in Access Score Model:
"Universities": [5,4,3,2,1,1,1,1,1,1],
"High Schools": [10,10,9,9,8,8,7,7,6,6],
"Primary Schools": [10,10,9,9,8,8,7,7,6,6],
"Kindergarten": [10,10,9,9,8,8,7,7,6,6],
"Occupational Schools": [5,4,3,2,1,1,1,1,1,1]

2) Hospital (Medical Services)
4649 observations in total. Categories of hospital include: clinics hospitals, outpatient facilities, emergency departments and disease control and prevention centers

Data dictionary used in Access Score Model:
"Clinics": [8,8,7,7,6,6,5,5,4,4],
"Hospitals": [10,10,10,9,9,9,8,8,8,7],
"Outpatient Facilities": [10,10,10,9,9,9,8,8,8,7],
"Emergency Departments": [8,8,7,7,6,6,5,5,4,4],
"Disease Control and Prevention Centers": [5,4,3,2,1,1,1,1,1,1]

3) Subway Station (Transit Access)
For the location-level model, transit access indicator is calculated by measuring the minimum network travel time between a location with its nearest subway station. For

[9] Beijing City Lab. 2017. *Points of Interests of China*. Retrieved from https://www.beijingcitylab.com/data-released-1/

the neighborhood-level model, the indicator is calculated using a constant weight of 10 for a single category of "subway" shown as below:
"subway": [10,10,10,10,10,10,10,10,10,10]

4) Air Quality

PM 2.5 as an important air quality indicator occasionally rose above 500 in certain areas of Beijing. This study uses NASA satellite imagery data MCD19A2[10]. 1 km Resolution MODIS AOD is a good estimator of ground-level concentrations over Beijing (Xie, 2015).

Location Data

Information regarding land zoned as Shared-Ownership Housing and commercial residential properties are listed in the Beijing Land Market website[11]. The study scraped land auction records since 2017 when the SOH programs were released. A land auction record contains information about location, transfer time, land owner, land use, selling price, transaction status and volume rate.

Neighborhood data

Neighborhood boundaries[12] is from the 2015 Beijing administrative division plan. 323 neighborhoods in total. The study dropped a neighborhood (ID: 314) because most of its area is Miyun Reservoir, the major water supply source of Beijing.

[10] National Aeronautics and Space Administration. (2019). MODIS/Terra+Aqua Land Aerosol Optical Depth Daily L2G Global 1km SIN Grid. Retrieved from https://ladsweb.modaps.eosdis.nasa.gov/search/.

[11] Land Market. (2019). Beijing Land Auction Record. Retrieved from https://land.3fang.com/market/110100_____1_0_1.html.

[12] Retrieved from https://download.csdn.net/download/georgeshanghaim1/10630075?utm_source=bbsseo.

Model Setting

Model Settings	Neighborhood	Location
Origin	Neighborhood Centroid	Residential Land
Destination	Point of Interest in Beijing	
Transit Type	Driving	Walking
Buffer Size (minute)	30	15
Facilities in Buffer	10	
School	Access Score	
Hospital	Access Score	
Subway	Access Score	Nearest Station (second)
Travel Speed	40 km/h	5 km/h

Table 1. Model setting of neighborhood-level and location-level analysis

Origin
Neighborhood-level model uses geometry centroids of 323 neighborhoods generated from boundary shapefile as origin to calculate travel time to the destination facilities. Location-level analysis uses Shared-Ownership Housing and commercial residential property locations as origin.

Network Type and Buffer Size
Beijing neighborhoods unlike tracts are relatively large in terms of size and population. The average area of a neighborhood is fifty-one square kilometers with an average population of sixty-seven thousand. Driving is determined as transit network type for neighborhood-level with 30-minute as the buffer size in order to capture the area and population of a neighborhood.

Location-level model instead uses a walking network with a buffer of 15-minute walking. The setting intends to follow the "15-minute Life Cycle" guideline brought by Beijing's "Thirteenth Five-Year Plan on Environmental Impacts of Transportation Development and Construction Planning", which plans to build an infrastructure environment where residents can have easy access to facilities in just 15 minutes by walking.

Subway Access Indicator
Considering the scarcity of subway station in suburban areas, a location-level model uses travel time to the nearest station as the index to evaluate access to subway. Neighborhood-level, instead, used the access score for subway consistent with school and hospital indicators since multiple stations might serve an individual neighborhood

and travel time to the nearest station from neighborhood centroid is not representative for its vast area.

Workflow (Location as Origin)

1. Data Preparation
    1) Scrape location data of SOH and CRH from Beijing Housing Authority website using Python;
    2) Reproject and merge subway station shape files using ArcGIS;
    3) Extract coordinates of schools, hospitals and subway stations and export to .csv files using R.

2. Spatial Access Model

The Spatial Access Model runs in Ubuntu Server with IPython notebook.

1) Travel-Time Matrix
    Input
        Origin (.csv): latitude, longitude and serial ID of Shared-Ownership Housing and Commercial Residential Housing units.
        Destination: (.csv): latitude, longitude, facility category and serial ID of schools, hospitals and subway stations.
    Output (.csv or .tmx): transit travel-time matrix (in seconds).
    Configuration: set transit type to walking; disable area threshold; test epsilon.
2) Access Score
    Input
        Dictionary: facility categories and weights for nearest facilities.
        Origin (.csv): latitude, longitude and serial ID of Shared-Ownership Housing and Commercial Residential Housing units.
        Destination: (.csv): latitude, longitude, facility category and serial ID of schools, hospitals and subway stations.
    Output (.csv): scores for each facility category and normalized pooled score for the amenity.
    Configuration: set upper threshold for buffer size; normalize generated scores.

Air Quality Workflow

1. Original Data Preparation
    1) Scrape HDF4 satellite data using Python;
    2) Convert HDF4 to GeoTIFF using Python and OSGeo4W command shell.

2. Raster Processing using R
    1) Merge GeoTIFF under the same date from four different tiles;
    2) Generate GeoTIFF of monthly average AOD;
    3) Transform projection and crop to Beijing boundary;
    4) Extract monthly AOD values for each location.

Results and Discussion

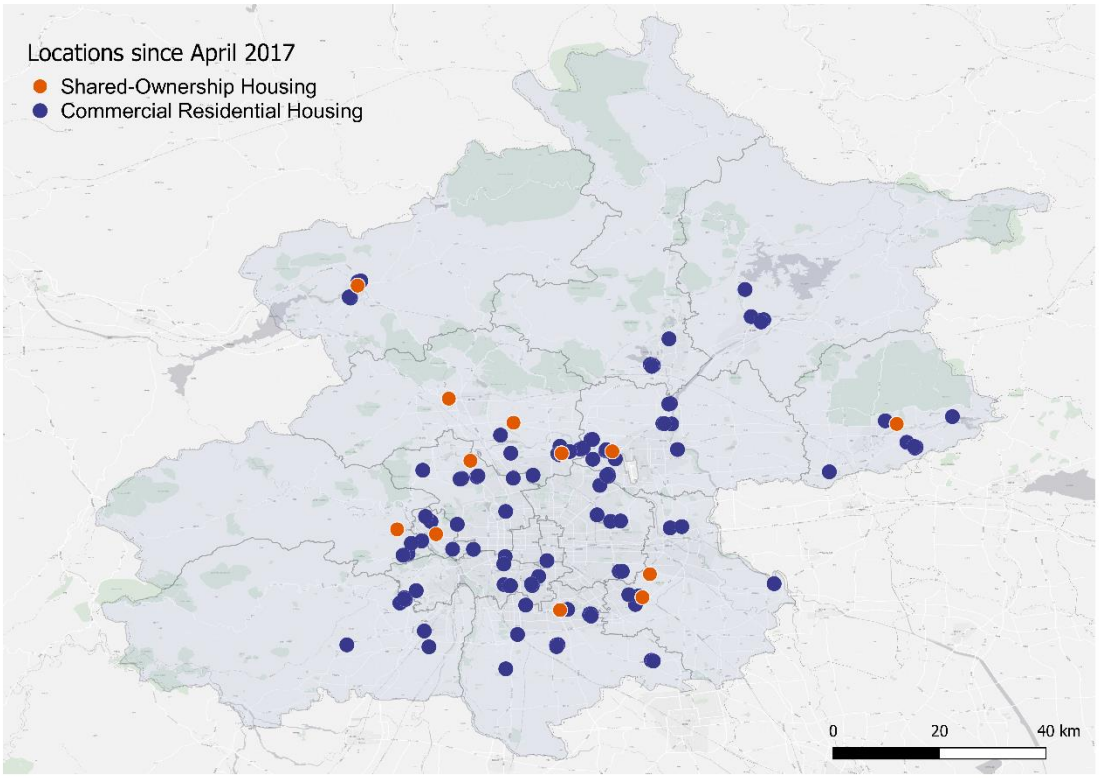


Figure 1. Shared-Ownership Housing (orange) and commercial residential properties (blue) locations

Figure 1 shows locations of commercial and Shared-Ownership land from April 2017 to April 2019. The recent auctioned residential lands show a spatial pattern of sprawling out for 20 to 30 km in all directions. New commercial residential properties are under construction in the northwest (Yanqing and Changping), northeast (Miyun and Pinggu) and the south side (Fangshan and Daxing). Shared-Ownership Housing has a similar pattern with the commercial residential properties by spreading out around downtown but more clustered in the northwestern districts of Yanqing, Changping and Haidian. It is worth noting that most of SOH sites have commercial residential properties in proximity.

The sprawling pattern of location proves Beijing's long-term efforts to evacuate residents from the crowded downtown by building up residential complexes in the suburbs. Suburban neighborhoods are notorious for their poor infrastructure and access to amenities and are perceived as not ready to house the huge influx of population.

Neighborhood Level

The study first examined the neighborhood-level access to school, hospital and subway transportation by using the Spatial Access Model in order to justify the general perception of the suburban neighborhoods.

Figure x to x present the variation in neighborhood-level accessibilities measured by Spatial Access Model. Blue triangles represent Shared-Ownership Housing locations

and black dots represent commercial residential locations. The grey area with missing data is Miyun Reservoir, the water supply source of Beijing.

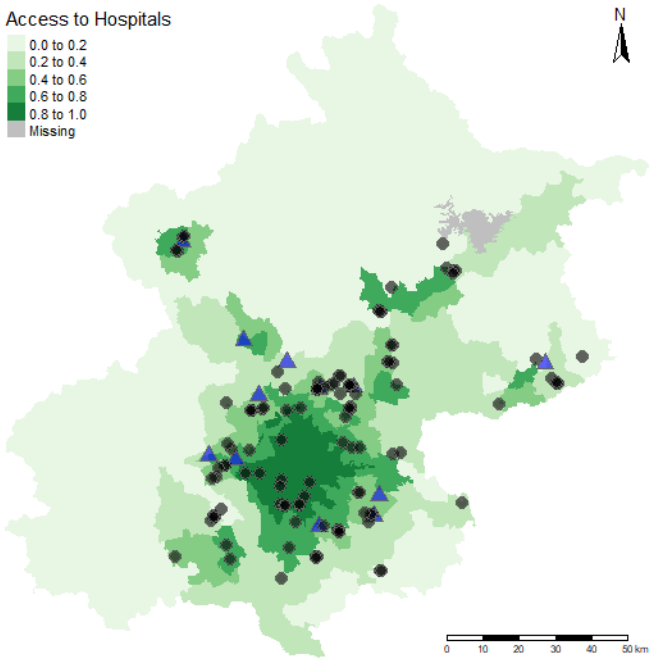


Figure 2. Neighborhood-level access score for hospitals

Figure 2 shows that hospital access score is significantly higher in and around the downtown area shaded dark green. The score decays rapidly as the distance between the measure neighborhood and downtown increases. Centers of suburban districts of Yanqing, Miyun, Pinggu and Fangshan also enjoy better access to hospital but the benefits are limited to the core district areas and unable to reach the remote neighborhoods. SOH locations are mostly in the neighborhoods with score of 0.2-0.4 or below, while commercial residential properties locate more in the dark green areas with access score from 0.6 to 1.0 due to its closer distance to downtown.

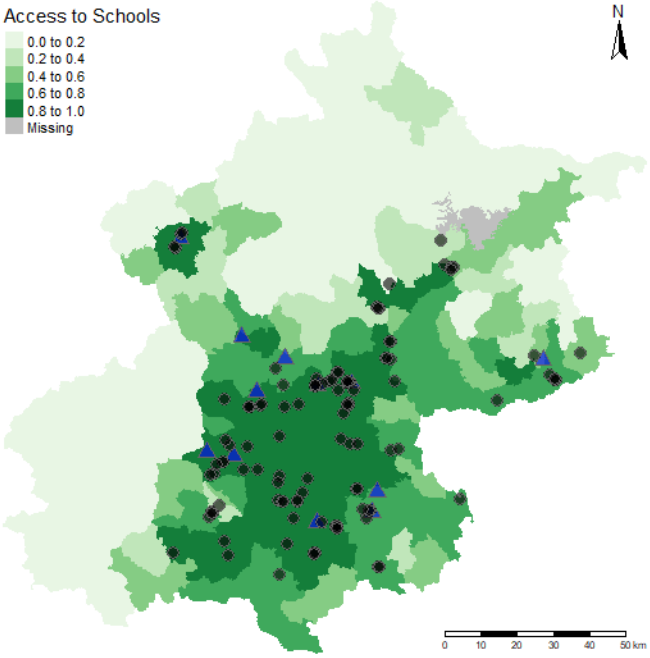


Figure 3. Neighborhood-level access score of school

School access score shown in Figure 3, however, present a better spatial equality at the neighborhood level. Neighborhoods overall enjoy good access to schools as the majority has scores from 0.6 to 0.8. The top quantile of the score (0.8 to 1.0) reaches neighborhoods that are 20 km away from city center. The score shows a very slow decay compared to hospital access score. Although a few SOH locations fall into lower quantiles like 0.2 to 0.4, most of the residential locations are in the neighborhoods in the top two quantiles.

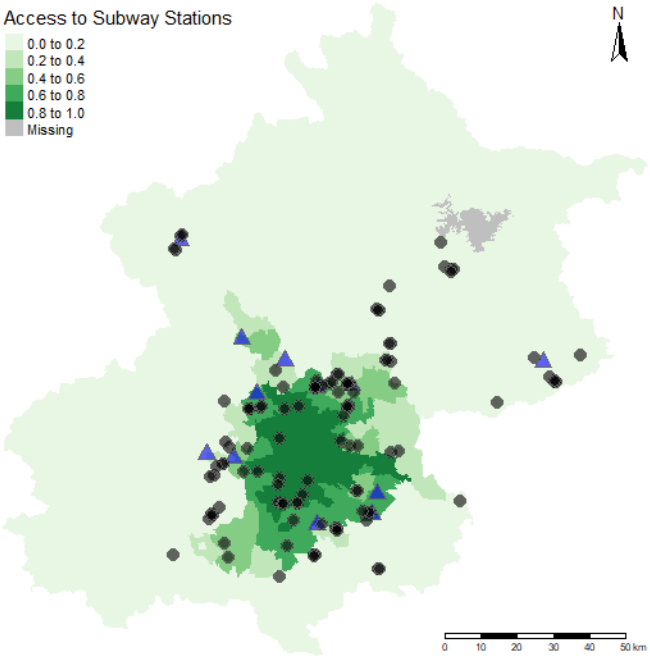


Figure 4. Neighborhood-level access to subway stations

The subway access score in figure 4 has a significant pattern of spatial clustering around downtown. The score plummets 40% to 60% only 15 km away from city center. Centers of suburban districts have poor access to subway and don't differentiate with nearby neighborhoods anymore. Most of SOH locations are in the lowest quantile while half of the commercial residential properties are in the darker area with higher subway station density.

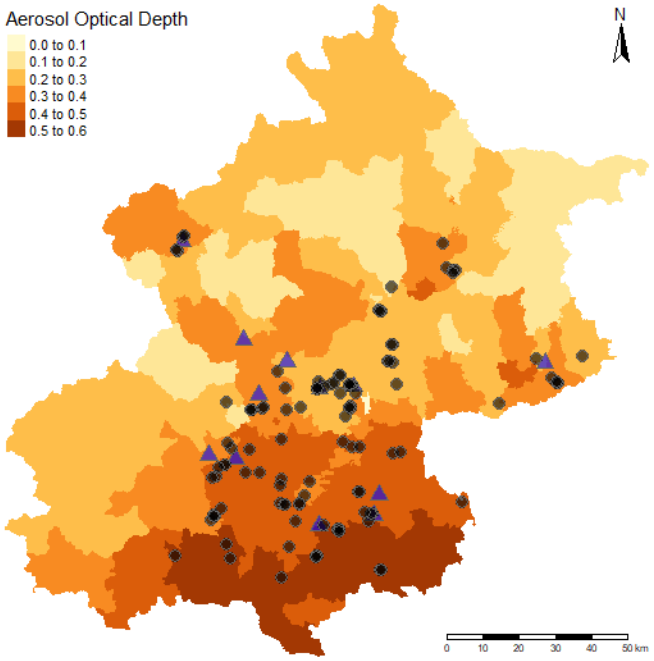


Figure 5. Neighborhood-level aerosol optical depth for air quality

Air quality simulated from aerosol optical depth data in figure 5 shows that neighborhoods in the southern areas generally have worse air quality compared to the north. The variation of the distribution, however, is not significant enough in the habitable areas between north and south. One issue is that the light yellow areas in the north are tend to be mountainous with low population density.

From figure 2 to 5, we see a clear pattern of spatial clustering around downtown among three access scores, especially considering access to hospitals and subway stations. Patients in suburbs have reduced accesses to medical care centers and major hospitals. Commuting by subway is still challenging for the working class that live far from downtown where most employers locate. Access to schools is surprisingly more equitable at the neighborhood level, which means the Beijing public school system has made considerable progress in building primary and high schools and providing education opportunities in suburban residential areas. It's reasonable for affordable housing applicants to persist in the perception that suburban neighborhoods have worse amenity accessibility.

This perception might result in the unwillingness of applicants to buy Shared-Ownership Housing properties since all SOH programs are located far from the city

center. Figures above show that SOH locations are generally in the neighborhoods with lower access score of hospital and subway. But it's not enough to conclude that Beijing Housing Authority is discriminatory in site selection. Spatial Access Model at neighborhood level uses neighborhood centroid as origin to calculate access score, while the centroids are not necessarily the locations of SOH programs and might have different accessbility.

Location Level

The study then used Spatial Access Model to directly examine accessibilities of 122 SOH and CRH locations.

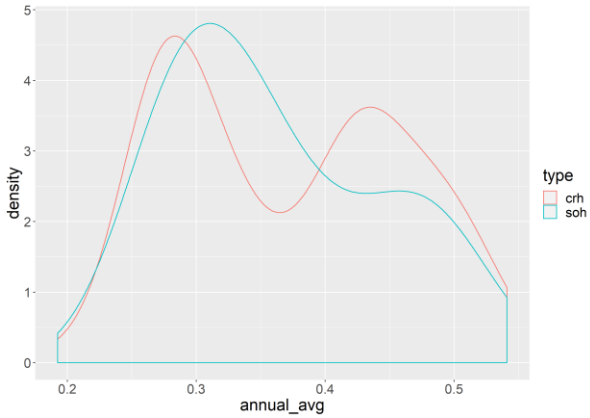
Type	CRH	SOH	p-value
Observation	110	12	
School (score)	0.267	0.304	0.773
Hospital (score)	0.218	0.218	0.986
Subway (second)	3906.227	3125.083	0.326
AOD (unitless)	0.370	0.362	0.734

Table 2. Mean and p-value of Welch Two Sample t-test for CRH and SOH

Table 2 shows the access indicators of schools, hospitals and subways. Shared-Ownership Housing locations on average has a slightly higher access score than that of commercial residential locations. It takes 781 more seconds for CRH to get to the nearest subway station. The two groups of location have the same access score to hospital of 0.218. However, all p-values from Welch Two Sample t-test are too large to reject the null hypothesis that true differences in means is equal to 0.

The table above indicates similar access to amenities for the two groups of location and even worse access to school and subway station for commercial residential housing locations.

a.



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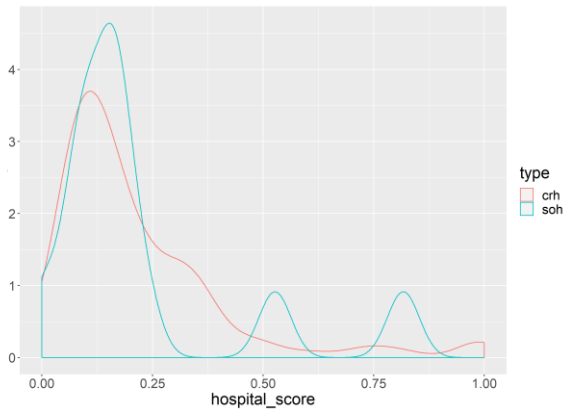

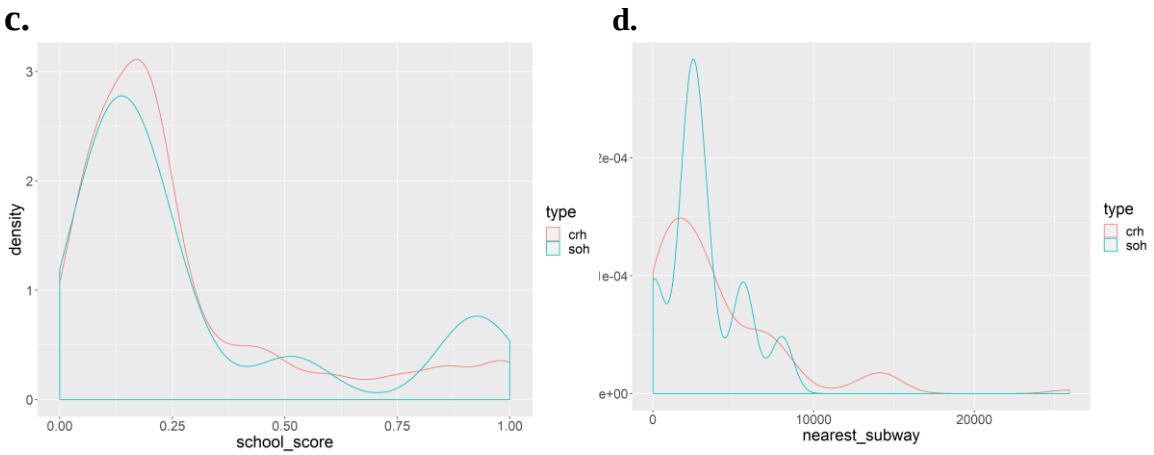

Figure 6. Distribution of access indicators: (a) Aerosol optical depth; (b) Hospital access score; (c) School access score; (d) Travel time to the nearest subway station.

Figure 6 presents the distribution of access scores for the 122 residential locations. CRH and SOH have similar school access score distributions that are skewed to the right and both peak around 0.25, but CRH has a heavier tail at the right-hand side towards 1.0. Distributions of hospital access score also skewed to the right and peak around 0.15. SOH's distributions of travel-time-to-nearest subway station fluctuates around the distribution curve of CRH with 3 peaks and a much higher density around the mean.

Distribution curves of CRH in figure 6 generally have a heavier tail to the right, which indicates though means of the access scores are statistically indifferent, more CRH locations have higher access score compared to that of SOH.

However, we can't conclude that SOH locations have better access to schools, hospitals or subways given that the sample means are statistically indifferent and density distributions are similar between the two groups.

Conclusion

At the neighborhood-level, we found that being farther away from downtown means worse accessibilities for residents. Compared to the more evenly distributed CRH locations, SOHs locations are all far from the city center and are mostly located in neighborhoods with low access scores. The perception of poor infrastructure in suburban neighborhoods might be one reason that has kept affordable housing applicants from being involved in SOH programs.

However, when examining the access score of the residential locations, we found no significant difference between the two groups of location. When limited to the local level, SOH's accessibilities are even better than those of CRH. In fact, the relatively large access score of SOH doesn't indicate SOH have good access to school, hospital or subway. Our results only confirm both types of recent auctioned residential lands have poor accessibilities.

Recommendation
The Spatial Access Model enables us to identify neighborhoods with good accessibility but currently without SOH programs. The question then becomes: where we could help Beijing Housing Authority place future SOH programs?

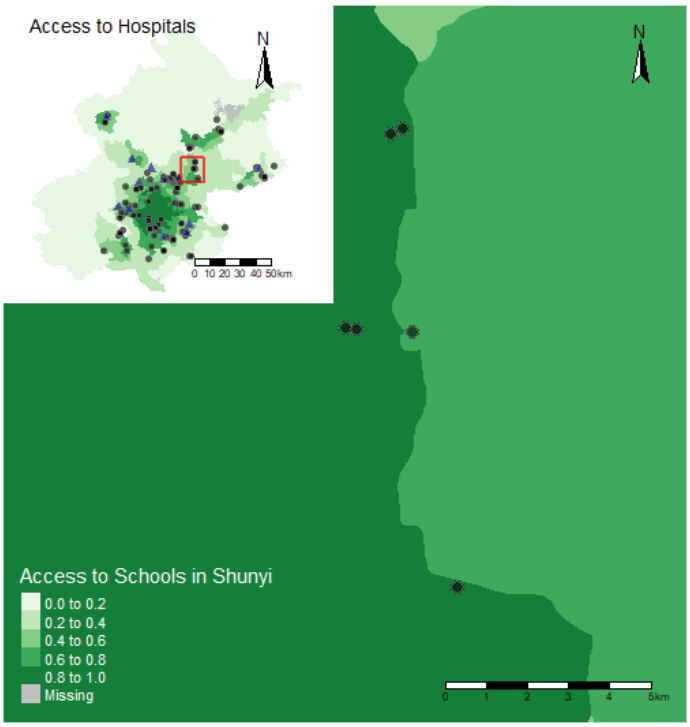

Figure 7. Northern Shunyi's access to schools and hospitals.

We recommend the northern part of Shunyi district, shown as the red rectangle in the inset map, could be an ideal candidate. Most of this area have top quantile access score to schools and good access to hospitals that scores above 0.6. Black dots are the recent auctioned commercial residential housing properties that spreading along the boundary between two neighborhoods, which implies residential area is expanding from west to east and there will be considerable vacant land for Shared-Ownership Housing programs.

Future improvement

Insignificant results might come from the small number of observations included in the dataset. Future research will update the Shared-Ownership Housing and commercial residential housing locations to increase the explanation power to see whether there is discriminatory site selection from the Beijing Housing Authority.

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