Understanding the potentials and challenges of subway developments for a new low carbon metropolis: A multi-scale approach

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A joint Tsinghua University-University of Cambridge team

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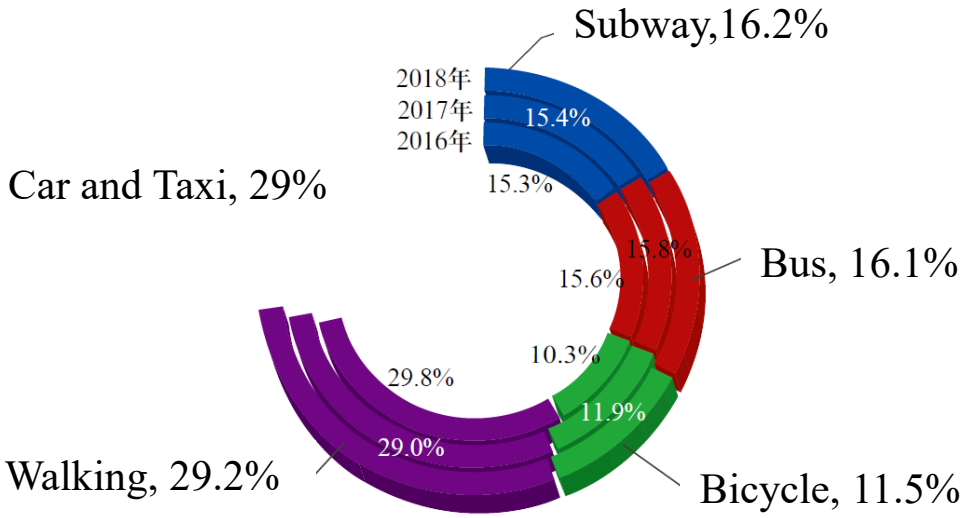
1. Background
2. Key questions
3. Conclusion

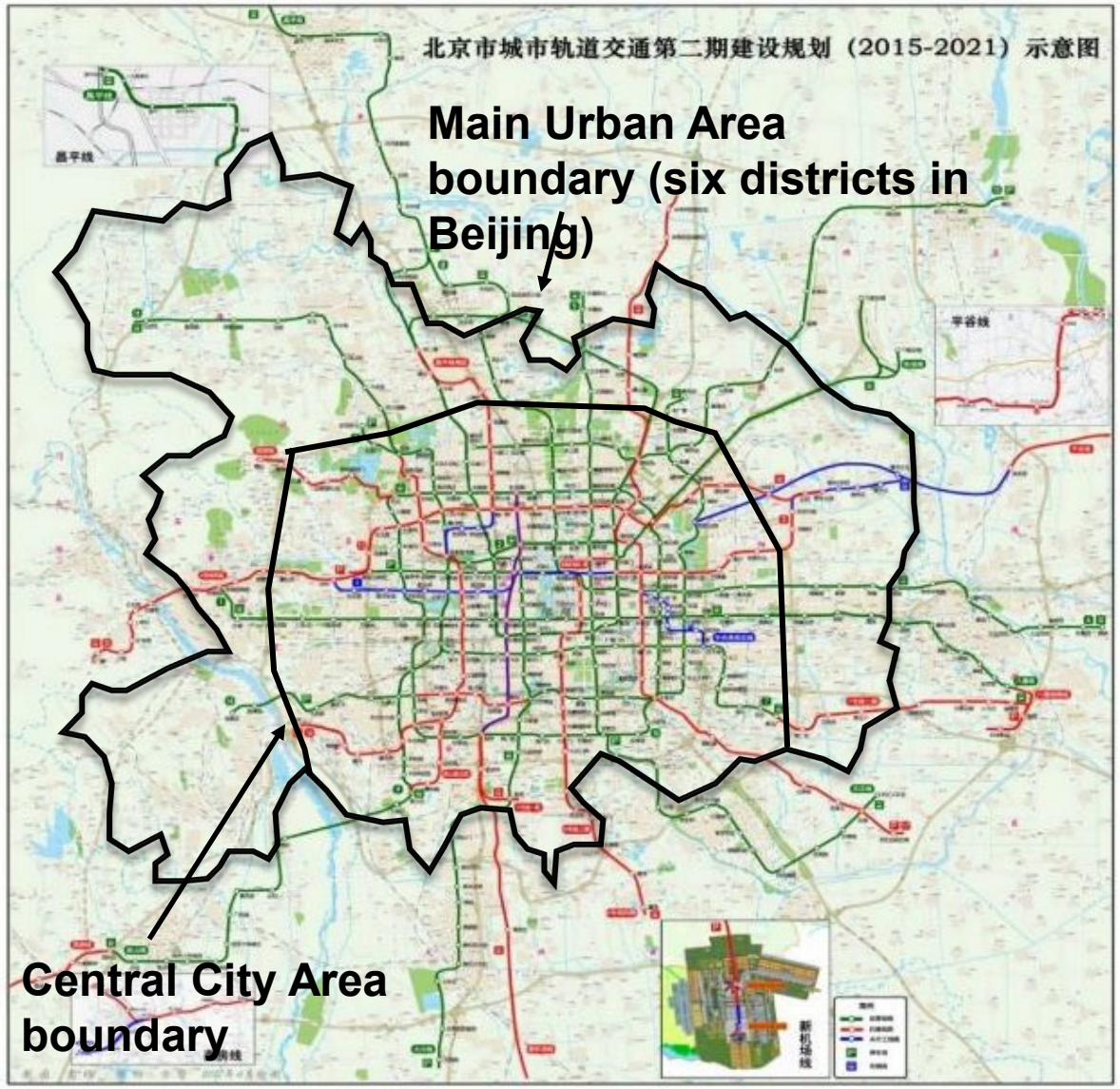
1. Background

Current situation

- **Rapid growth of Beijing's subways.**
  - At present, 19 lines are in operation with 574km track-kms and 345 stations; 11 million passengers on an average working day; The total planned track-km of subways will reach 998.5 km with 550 stations.
- **Current share of subway travel is not that high.**
  - In the Main Urban Area, subways only carry 16.2% of the total daily trips in 2018, but the share is growing.



Mode share (trips) in Main Urban Area of Beijing (2016-2018) (six districts in Beijing)



1. Background

Policy objectives

- **Build a polycentric urban structure** through the development of suburban new towns and decentralization of the Central City.
- **Integrate land use and rail transit through a TOD model** to achieve sustainable development and reduce urban congestion.
- **Increase land-use (residential & commercial) efficiency around subway stations** - at present subway station catchment areas (400m radius from operating stations) accommodate 15% of the total population and 22% of the employment.

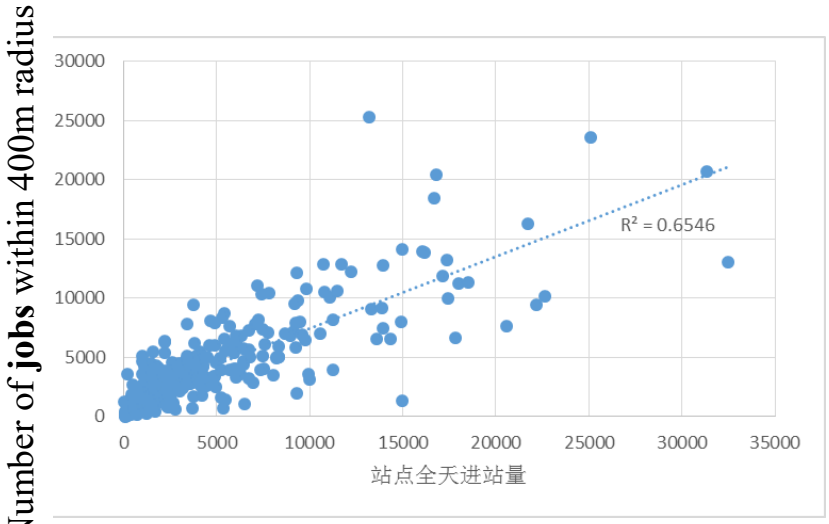
1. Background

- **Key questions**
  - **尺度：在多大范围内优化开发强度/用地功能是更有效的?**
  - **Scope:** what is the appropriate spatial scope for developing and implementing an effective density and land-use strategy around subway stations in Beijing?
  - **分类：如何识别站点的差异性，实现有针对性的开发强度和土地利用的优化**
  - **Classification:** how to classify the variety of subway stations in terms of location, existing land-use pattern and network property?
  - **影响：未来轨道站点周边用地优化取得何种社会经济效果?**
  - **Social-economic impacts:** What are the social-economic impacts of enhancing TOD at different spatial levels?
  - **形态：在站点周边地区上调开发强度的城市形态是什么样的?**
  - **Urban form:** How would the urban form look like after increasing building density around the subway stations?

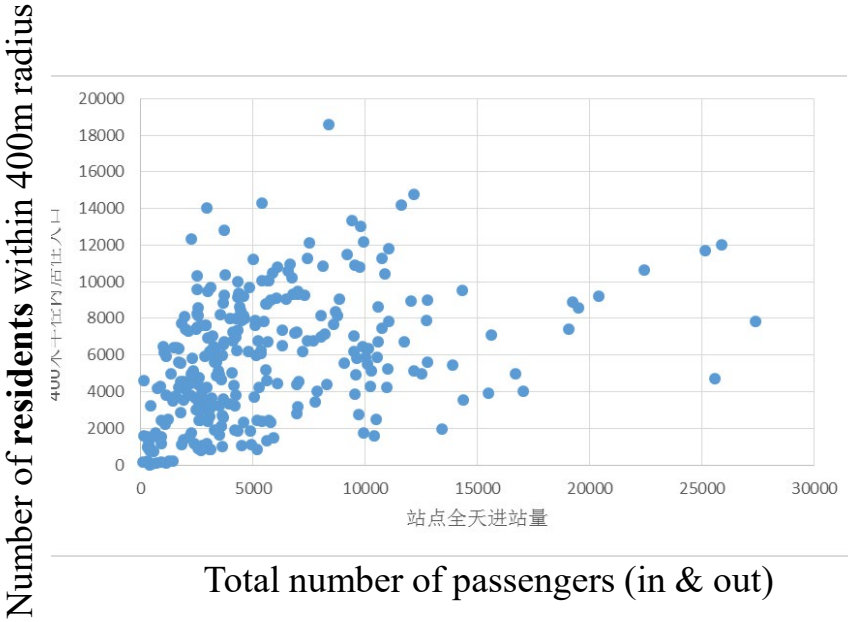
2. Key Questions

2.1 Scope

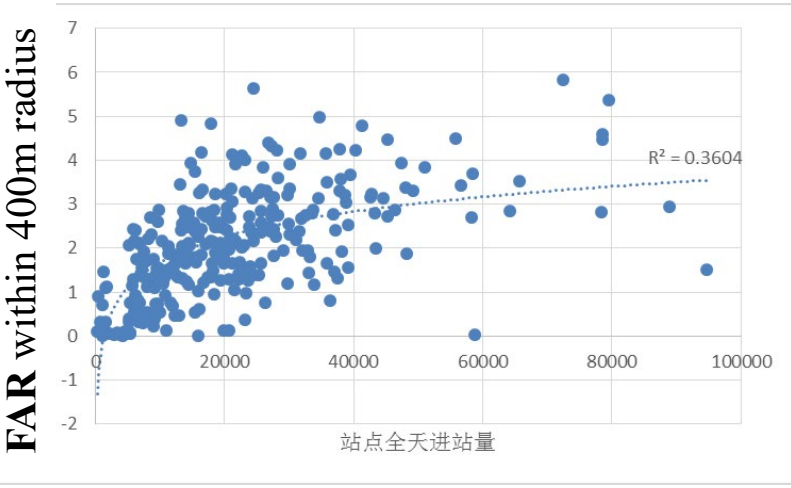
- **北京地铁站点出入站客流量与商业建筑容积率、土地混合度、换乘条件、就业和居住人口规模显著相关**
- The total passenger flow throughput (both in and out) of Beijing subway stations are significantly correlated with surrounding employment, and they are also correlated with surrounding residential population and the FAR of commercial/office buildings in the catchment areas (400m radius).



Total number of passengers (in & out)



Total number of passengers (in & out)



Total number of passengers (in & out)

2. Key Questions

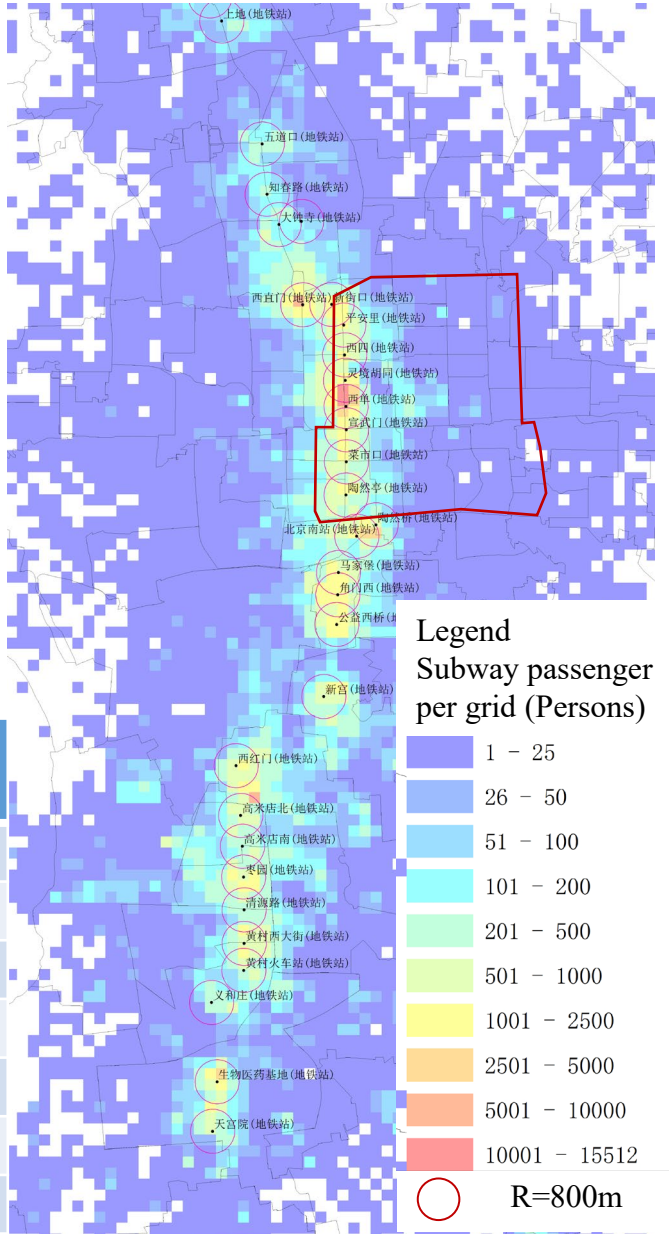
- **Subway station catchment area in Beijing: 400-800 meters radius**

Example: Subway Line 4, a radial line that runs north-south through the Old City, the rest of the Central City and the new town of Daxing

According to movements data distilled from mobile phone traces (400m grid, China Unicom):

- Subway travel within a radius of 800 meters accounting for about 50% of the total, and the incidences of subway travel fall rapidly beyond 800 meters.
- It should be noted that 27.5% of the total subway trips originate from/destined for 2km away from the station, which involves access by bus, taxi and bicycle.

Radius (m)	Subway passenger (000 persons/day)	Share	Average subway passenger per non-zero grid (persons)
<400	128	27.5%	937
400-800	107	22.8%	306
800-1200	57	12.3%	141
1200-1600	29	6.1%	65
1600-2000	18	3.8%	45
>2000	129	27.5%	13
total	467	100.0%	41



2. Key Questions

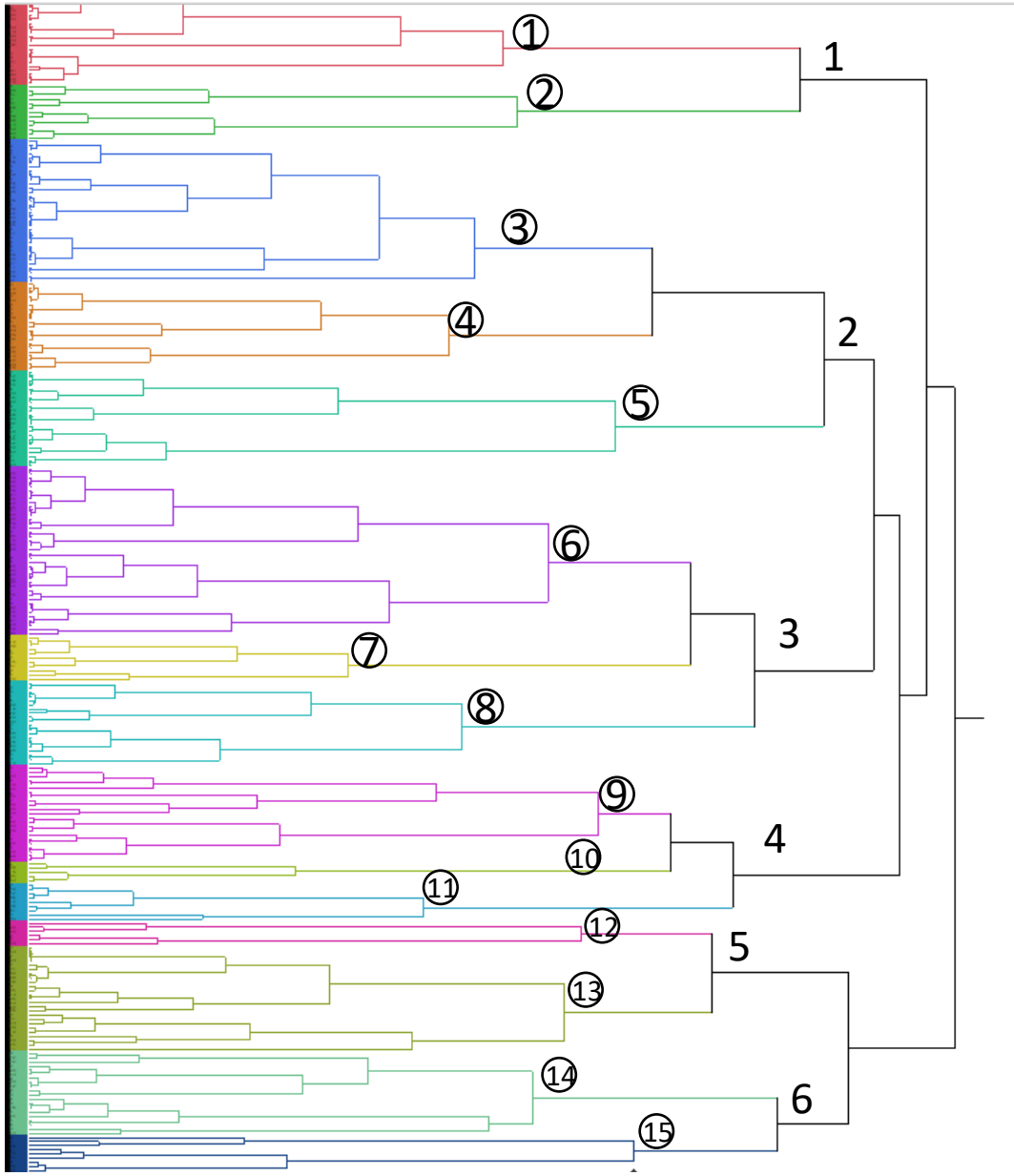
2.2 Classification of stations

北京以现状站点分类——观察北京既有站点的聚类特征。

- **Cluster analysis based on the following six key factors**

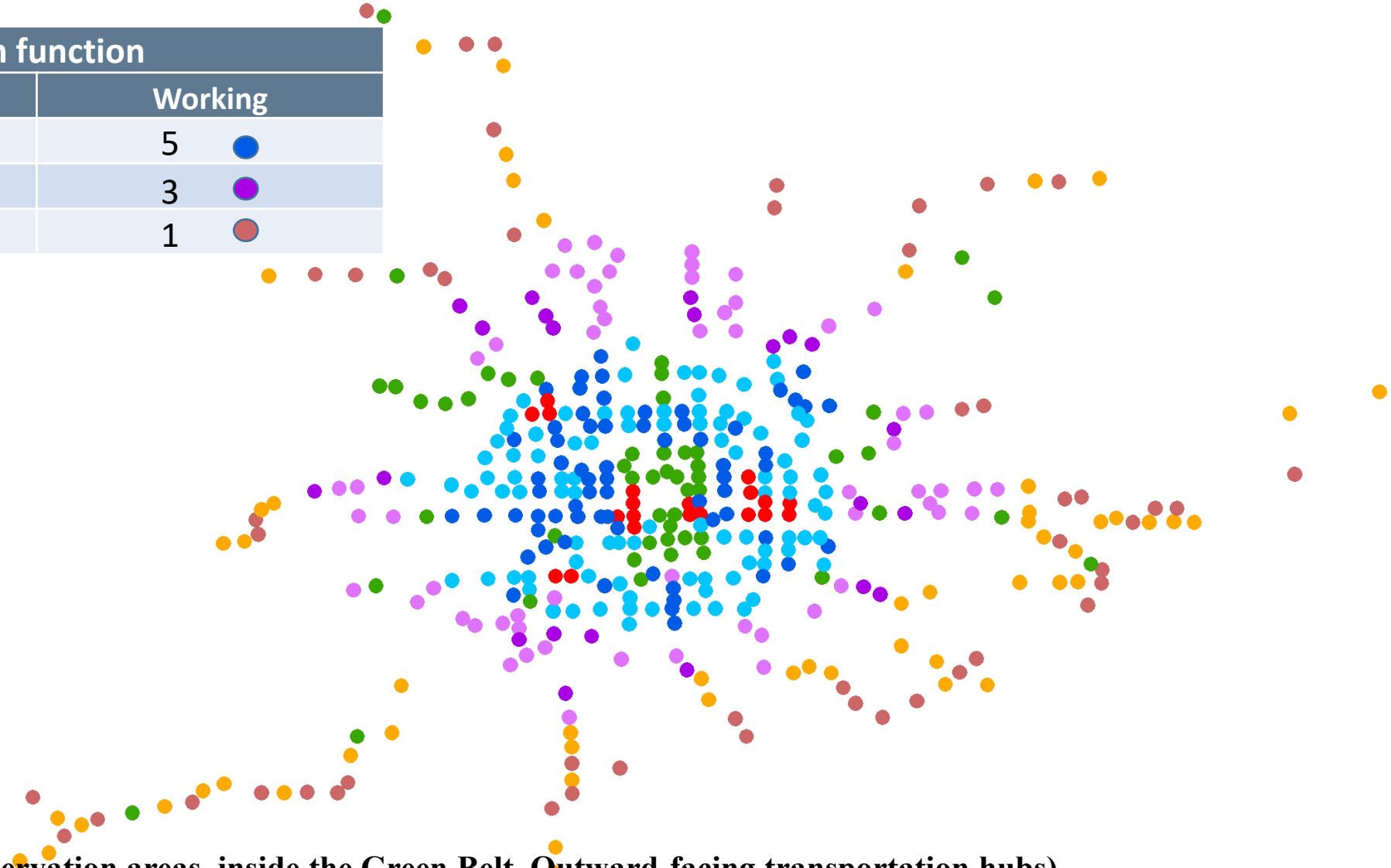
- Transfer capability (single line, two lines or more)
- Centrality (average distance to all stations)
- Total FAR (800m radius around the station)
- Proportion of residential land (800m radius around the station)
- Proportion of office land (800m radius around the station)
- Proportion of retail land (800m radius around the station)

- **309个站点：6大类，15小类**
  - 309 sites: 6 categories, 15 sub-categories



2. Key Questions

Location	Main function	
	Living	Working
Central Urban	6	5
Inner suburb	4	3
Outer suburb	2	1



1：Outer Suburb employment
2：Outer Suburb residential
3、Inner Suburb employment
4、Inner Suburb residential
5、Central Urban employment
6、Central Urban residential
7、City center station
8、Others (special stations in conservation areas, inside the Green Belt, Outward-facing transportation hubs)

2. Key Questions

2.3 Quantifying social-economic impacts through modelling spatial equilibrium recursively

A new model with distinctive roots in established urban models

MEPLAN model
(Echenique, 2004; Echenique et al, 2013)

Spatial input-output, building stock inertia, integrated transport choices

Spatial Interaction Models
Wilson (1967; 1970), Batty (1976), Batty et al (2013)

Correction of biased spatial observations

Computable General Equilbrium models
Brocker (1998); Anas and Liu (2007),

Producer costs and consumer utilities

Urban dynamic models
Allen (1997), Wegener (2001), Simmonds, Waddell and Wegener (2013)

Insights into non-equilibrium processes

Urban data analytics of travel, rent and activity patterns
SIMULACRA (Batty et al, 2013), Wan et al (CEUS paper), Hillel (2018), Yang et al (2020)

New data sources for model calibration and validation

Recursive Spatial Equilibrium (RSE) Model
(Jin et al. 2013; Rong, 2016; Ma, 2016; Deng, 2016; Wan, 2016, Wan & Jin, 2017, Jin et al, 2017)

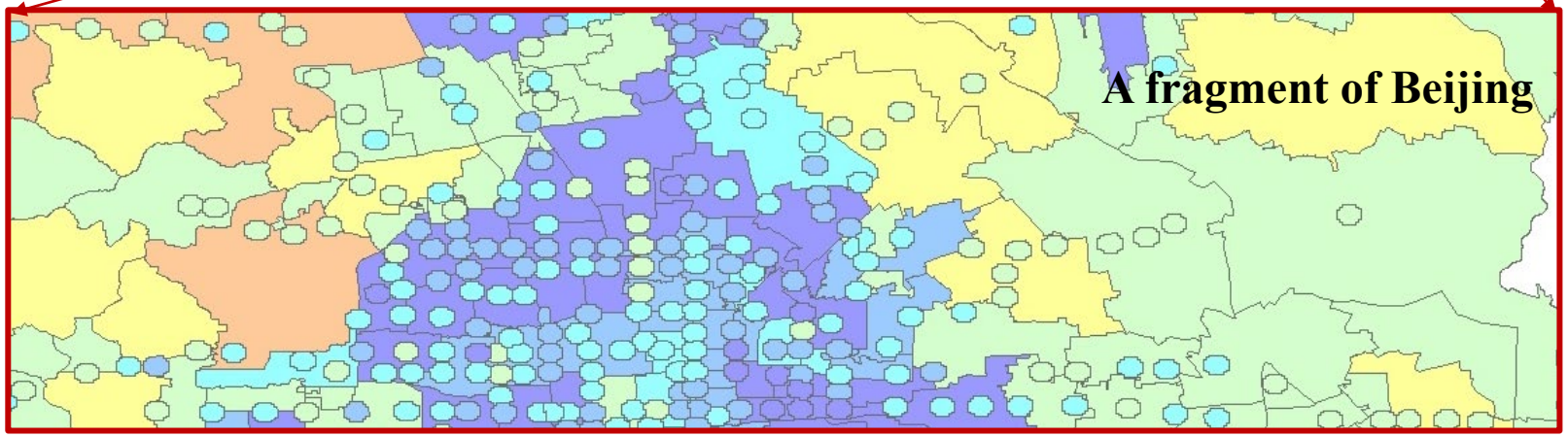
RSE Beijing model - What is new:

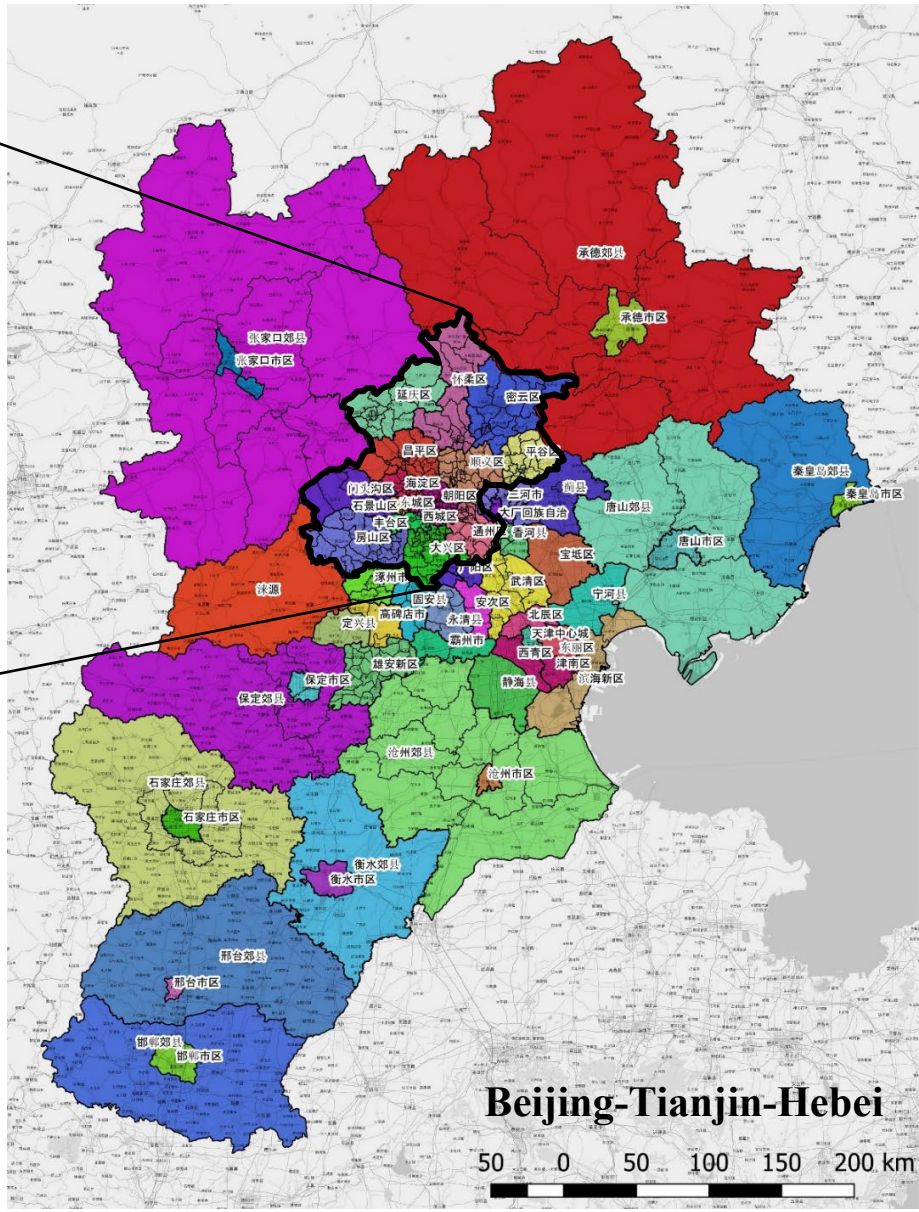
- Model calibration and validation over multiple time periods to finetune and validate the model (see Wan & Jin, 2017; Ma & Jin, 2018): Model calibration for years 2000 and 2010, run model in prediction mode for 2016 and 2018 to validate it
- Recursive predictions of building stock constraints, locations of non-employed residents in the city region
- Transport supply and travel time assumptions to account for user adaptations
- Hicksian (rather than Marshallian) utility functions to account for the tendencies for residents to resist falls in consumer utility as housing rents rise in an affluent city region

2. Key Questions

- **Model zones**

	Number of model zones
Beijing	755
Station zone	420
Non-station zone	335
Tianjin province	21
Hebei province	120
Total Jing-Jin-Ji	896

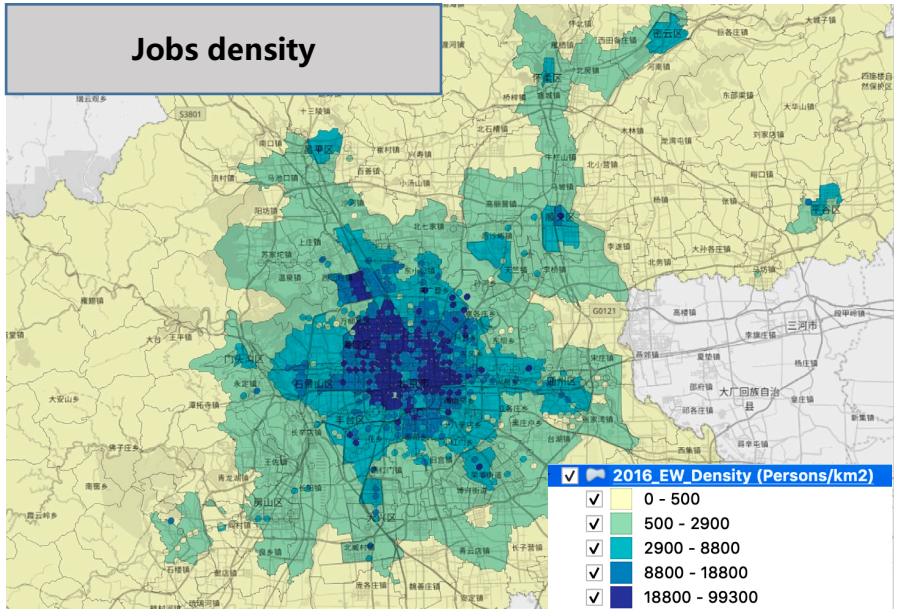




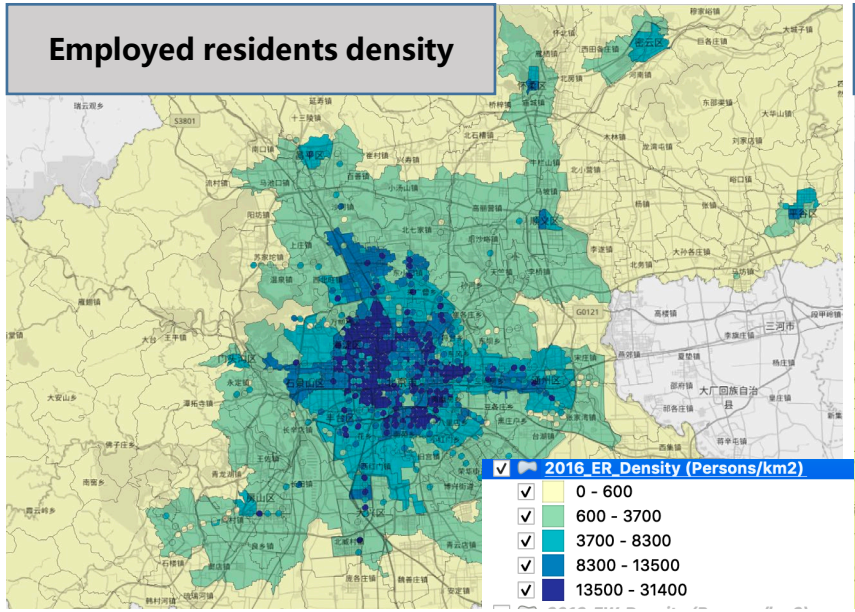
2. Key Questions

- **Base-year of 2018**

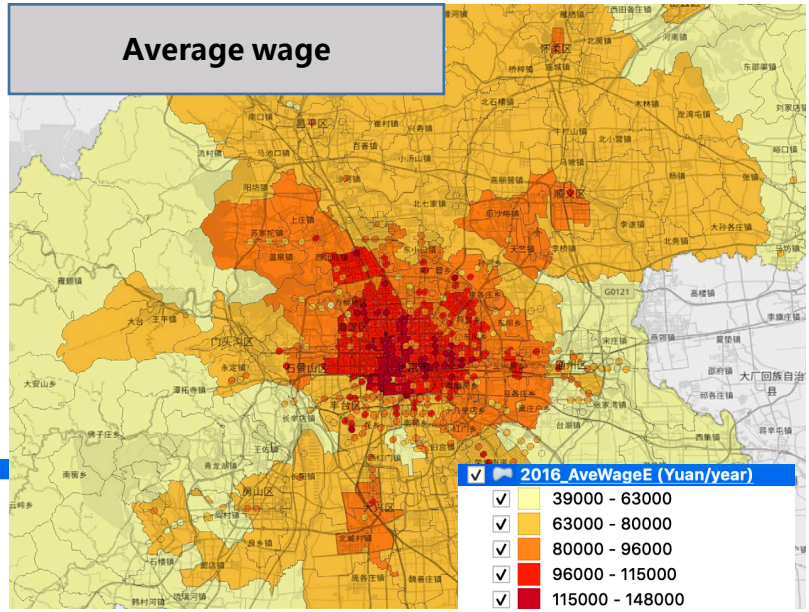
Jobs density



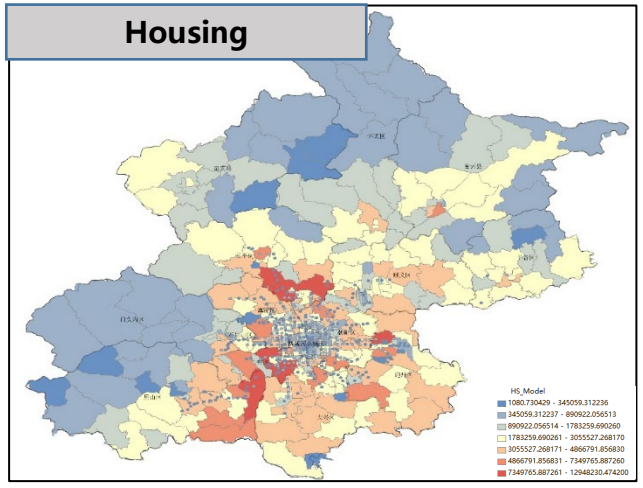
Employed residents density



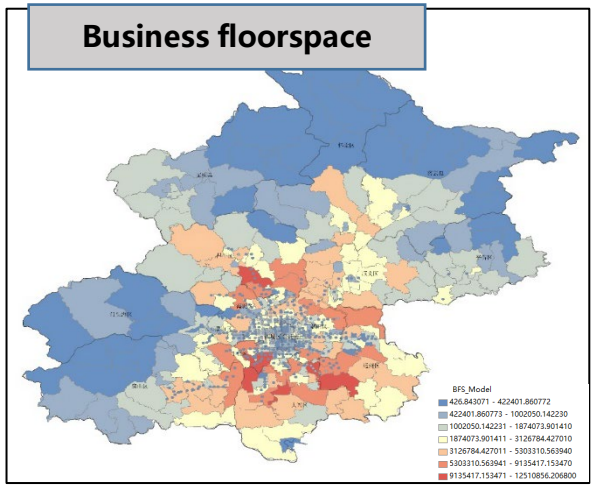
Average wage



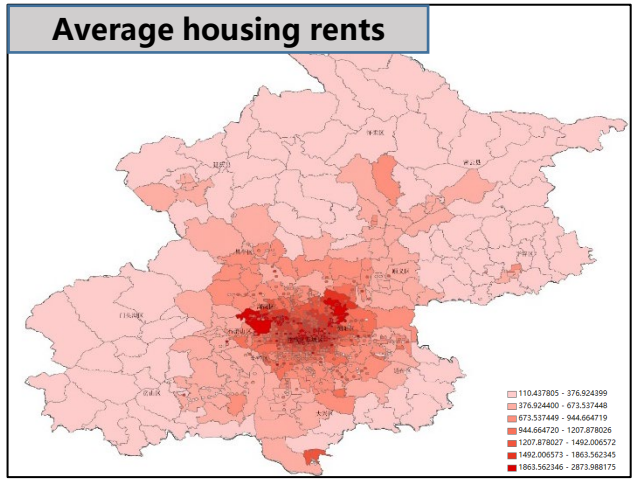
Housing



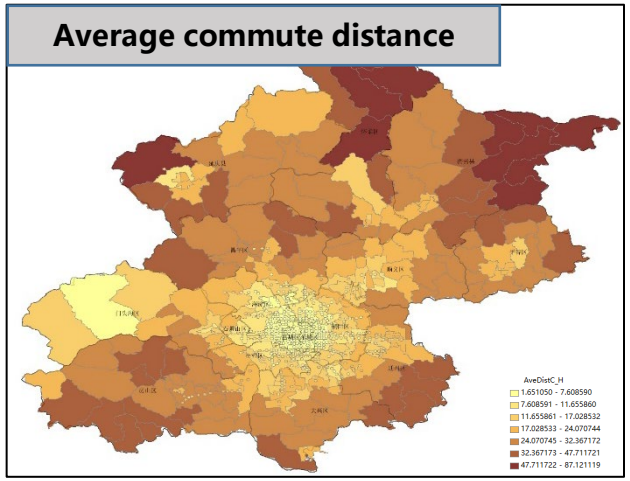
Business floorspace



Average housing rents



Average commute distance



2. Key Questions

- **Future development assumptions for Greater Beijing to 2035**

Assumptions are made according to the Masterplan of Beijing 2035 and observed trends in Tianjin and Hebei

- Average annual growth of jobs: 1.0%
- Average annual income growth (as a proxy for GDP): 5.1%
- Growth in floorpsace is assumed as follows:

	Annual growth rate 2018-2035	
	Housing (as one composite type)	Business floorspace (4 types)
Beijing	2.0%	2.3%
Tianjin	2.0%	2.0%
Hebei	2.0%	2.0%
Total	***2.0%***	***2.1%***

2. Key Questions

- **A multi-scale analysis**

City level

着重观察郊区站点用地优化，对于中心城人口疏解和多中心城市结构的影响

Focus on the city-wide effects on the size and spatial distribution of population, urban spatial structure and commuting patterns.

Subway line

着重观察一条轨道线的线内平衡的效果，并评估对线外区域的影响

Focus on the effect on job-housing balance and property rents along the subway line and the surrounding area.

Subway station

着重观察单点车站优化的溢出效应

Focus on the spillover effects on property rents and local commuting patterns near selected subway stations.

2. Key Questions

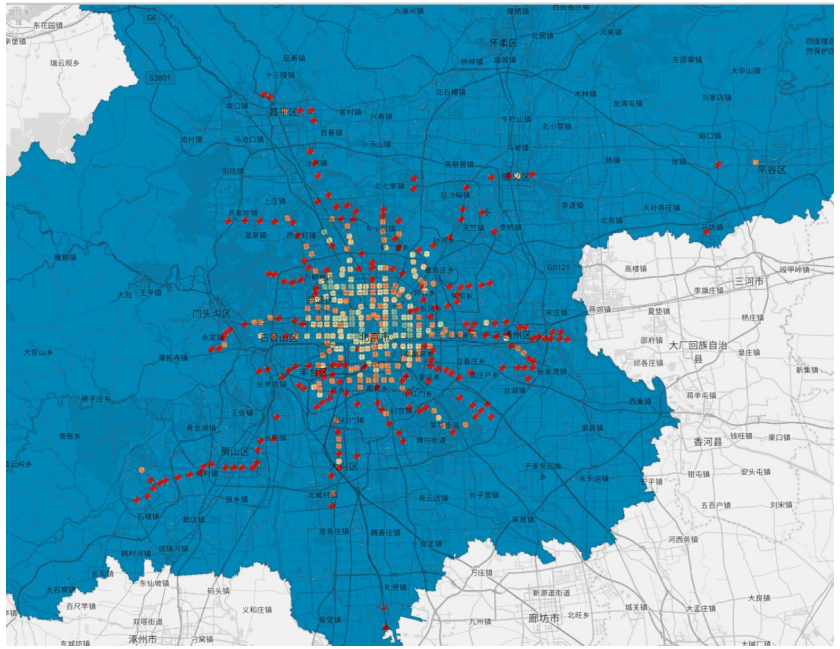
City level simulation

Scenarios S1\S2\S3\S4:

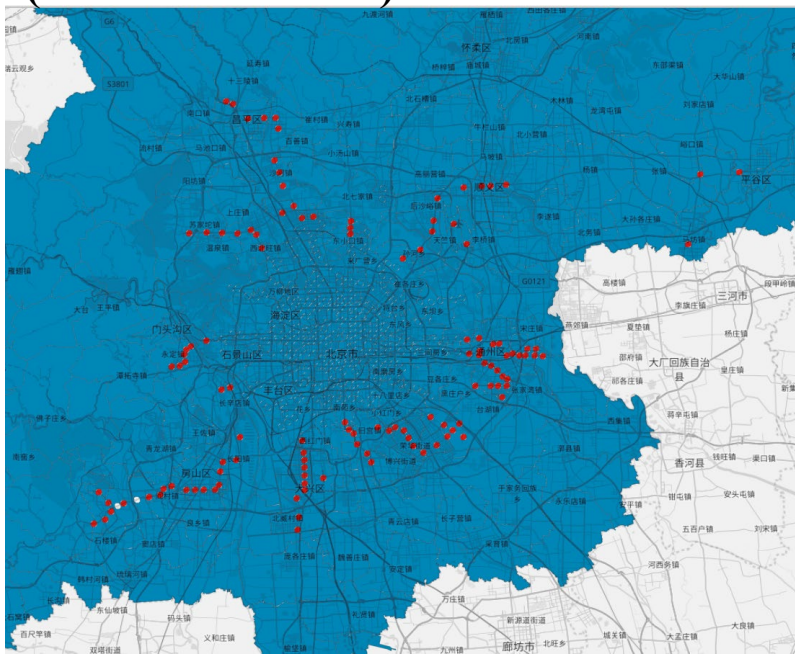
- Study area wide building stock growth remains constant
- New buildings are distributed differently among stations according to assumptions of each scenario

S1：Baseline scenario – land use plan of Beijing 2035: no special interventions in station areas

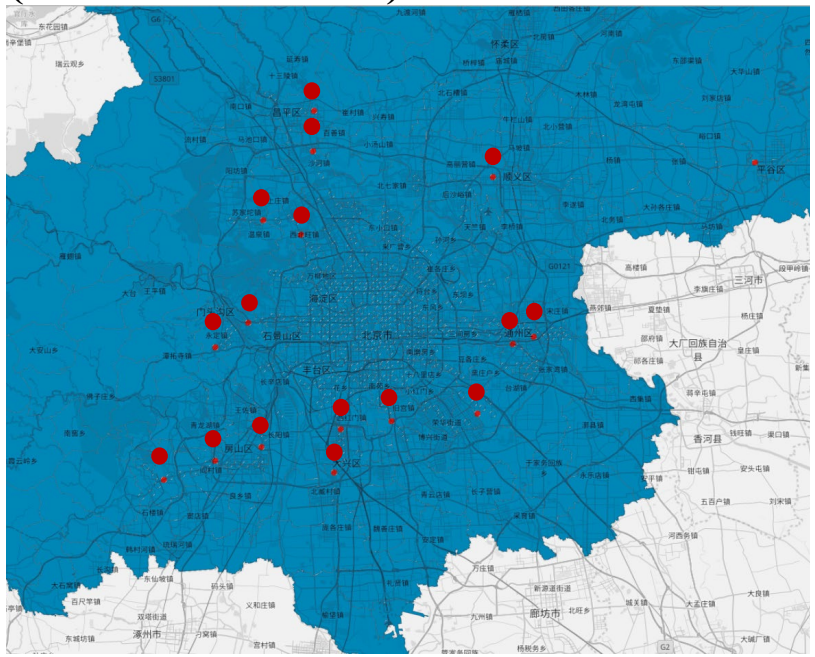
S2：全站点优先
Policy oriented growth in all stations (FAR +25%)



S3：郊区站点优先
Policy oriented growth in suburban stations only (FAR +50~100%)



S4：郊区特选站点优先
Policy oriented growth in selected suburban stations only (FAR +100~150%)

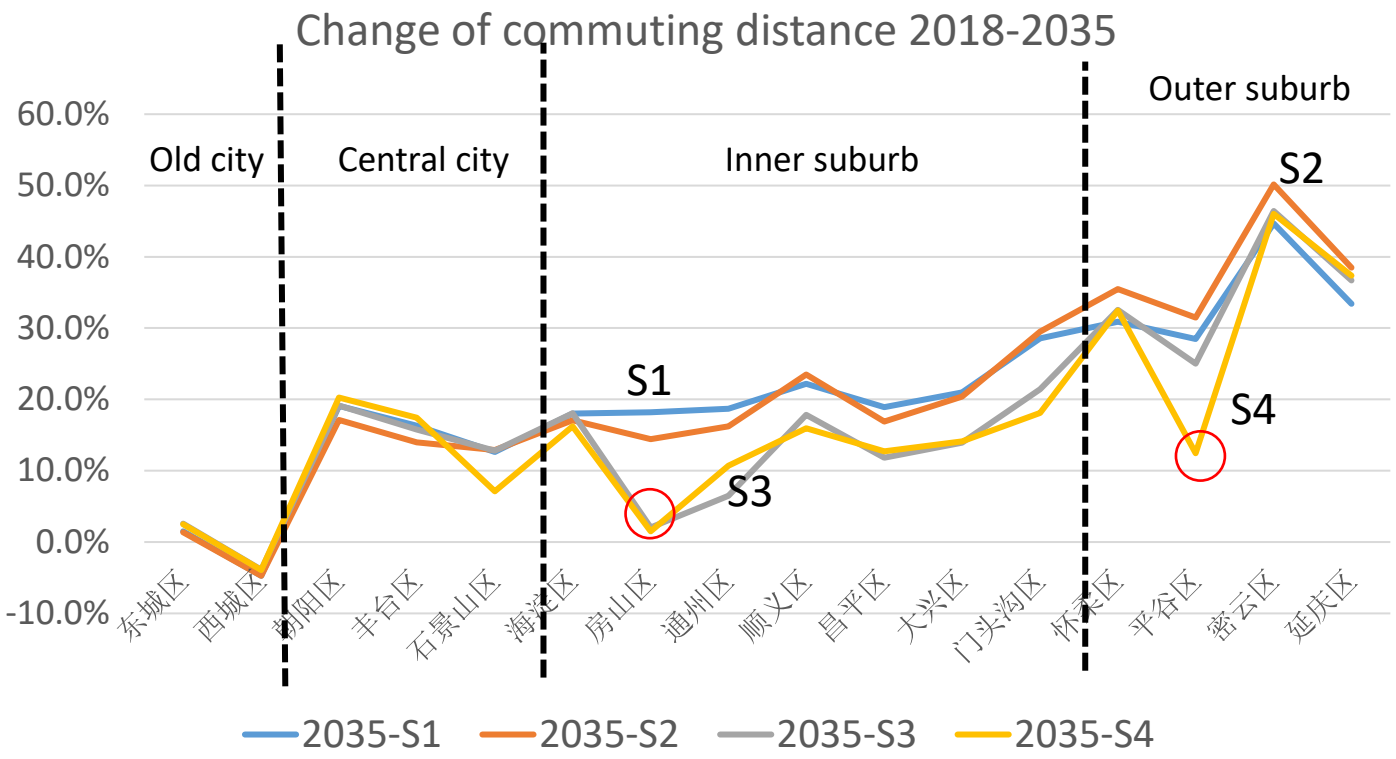


2. Key Questions

City level simulation

Change of commuting distance 2035 vs 2018

- S3 (Suburban station priority) will reduce local commuting distance by 5-15%
- S4 (Selected station priority) will reduce local commuting distance by 10-20%



2. Key Questions

City level simulation

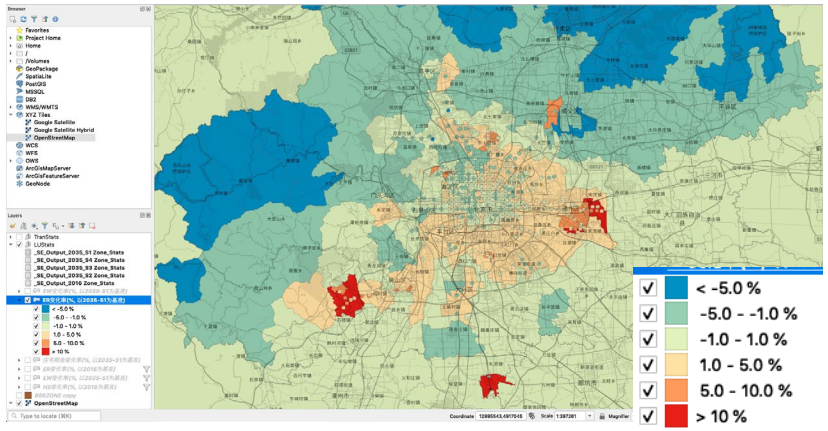
Change of population 2035 vs 2018

Because the total amount of floor space is the same across the study area in all scenarios

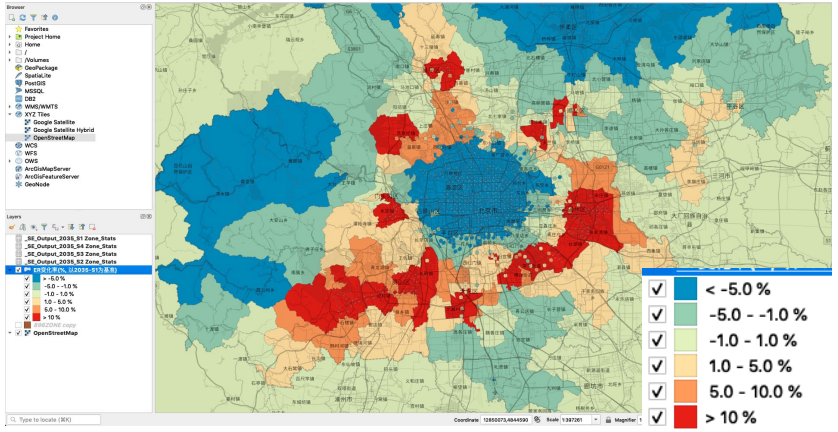
- Increasing business floorspace development around the suburban stations will serve to attract jobs away from the Central City by 1-5% compared with the Baseline Scenario (S1).

- In the suburbs, concentrated development around selected stations can prevent the urban sprawl along the Sixth Ring Road in Beijing.

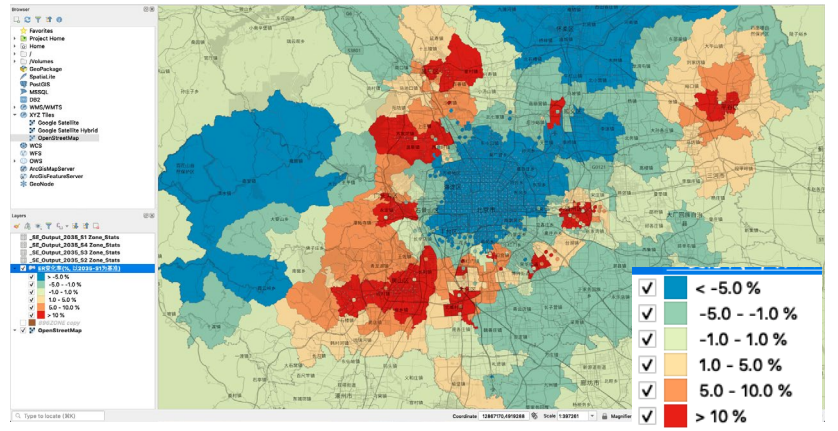
Employed worker change (S2 vs S1)



Employed worker change (S3 vs S1)



Employed worker change (S4 vs S1)



2. Key Questions

Single line simulation

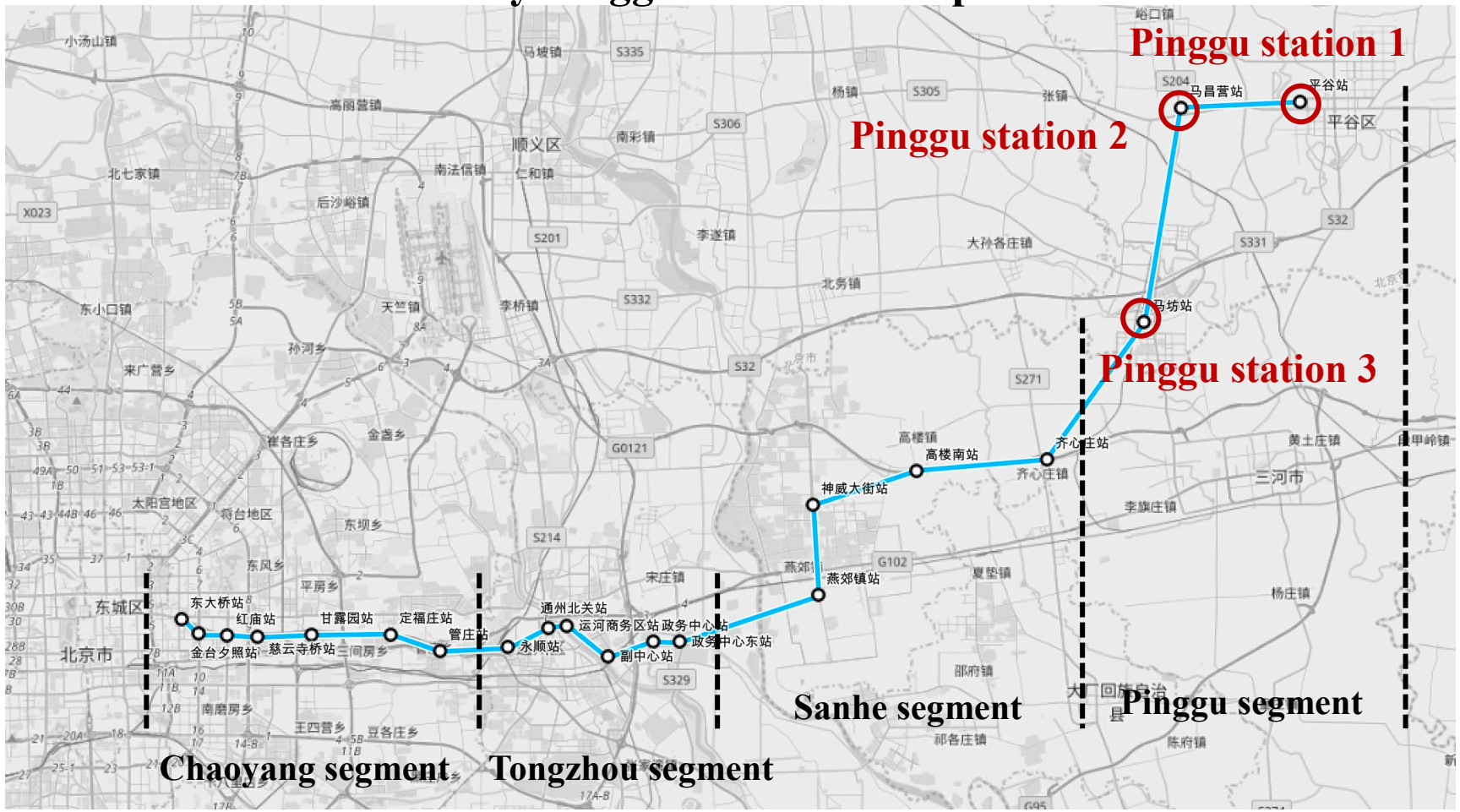
S1：Baseline scenario

land use plan of Beijing 2035

S2：平谷三站优先
Policy oriented growth in selected Pinggu stations (FAR +20%)

S2：全线站点优先
Policy oriented growth in all Pinggu Line stations (FAR +20%)

Subway Pinggu Line as a sample



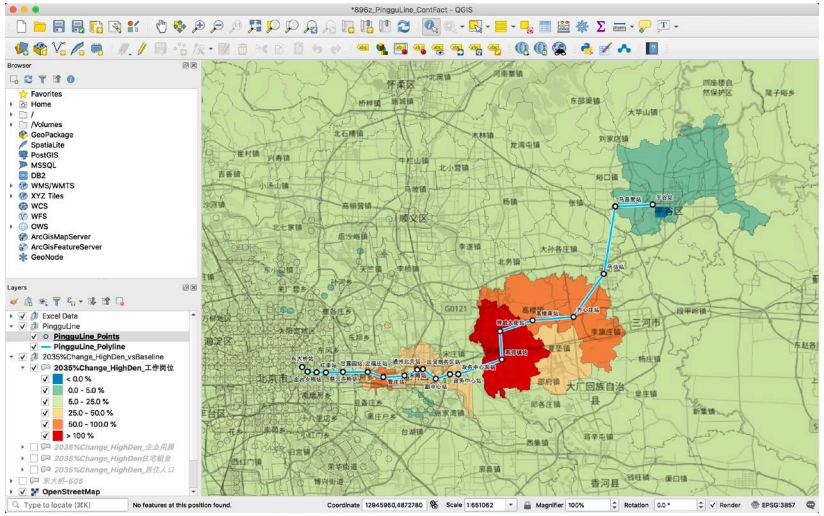
2. Key Questions

Single line simulation

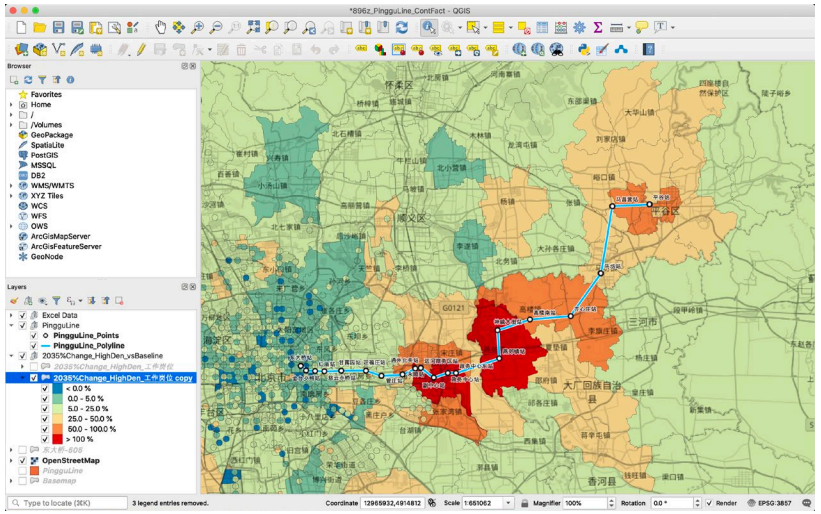
Enhanced station catchment development for the Pinggu line will:

- Boost jobs, residents and housing rents, although not all stations respond the same way;
- Relieve development pressures in the Central City;
- Reduce the average commuting distances, in particular for suburban locations along the subway/rail corridor.

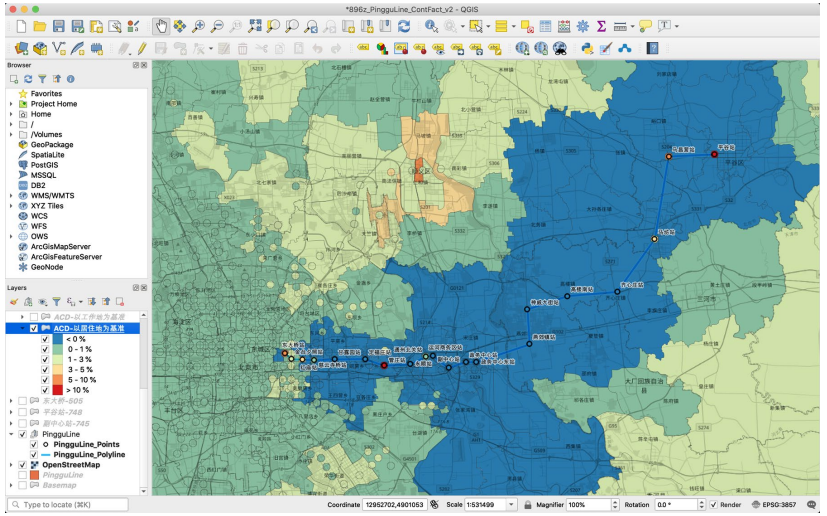
Employed residence change (S1 vs 2018)



Employed worker change (S1 vs 2018)



Commuting distance change (S1 vs 2018) (from living to job)

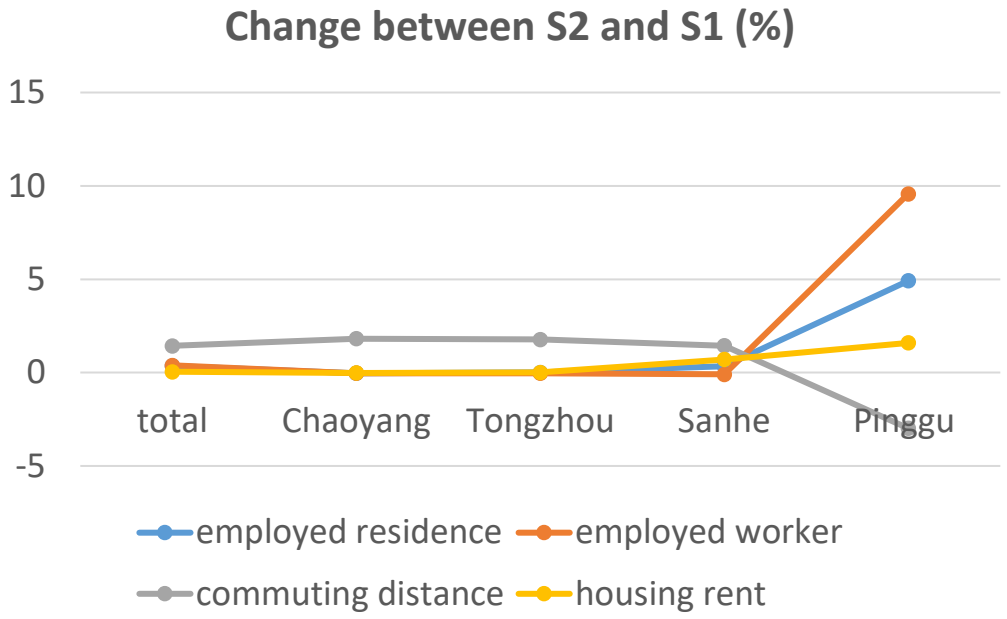


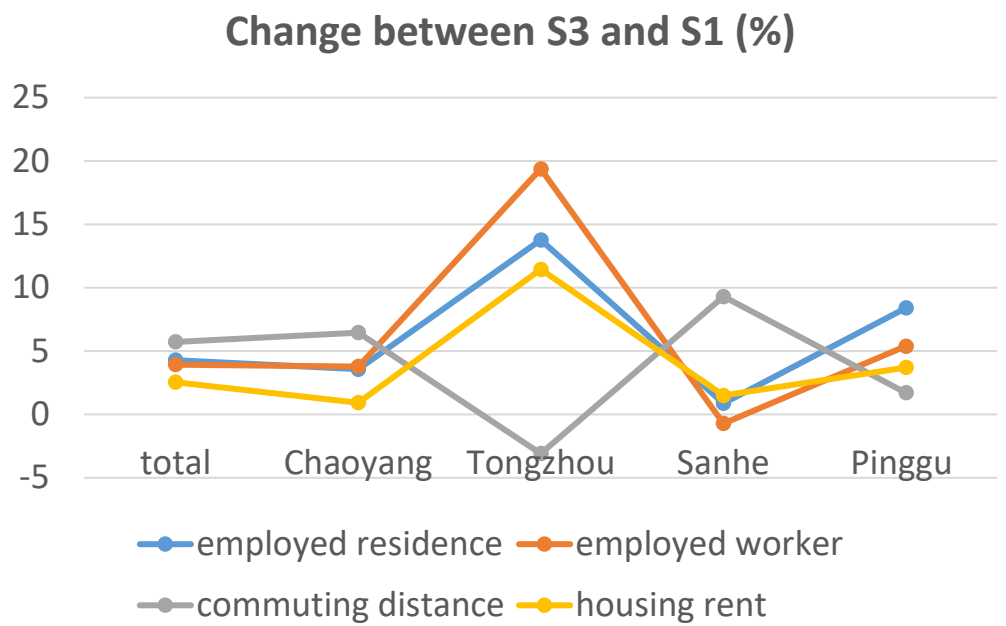
2. Key Questions

Single line simulation

- S2 (Pinggu three stations) vs Baseline: the impact on **Pinggu new town** is particularly significant. In Pinggu, the number of employed residents increased by 5%, the number of jobs increased by nearly 10%, the commuting distance decreased by about 3%, and the housing rent increased by about 1.6%.

- S3 (All Pinggu Line all stations) vs Baseline : larger effects along the whole line, and the impact on Tongzhou municipal sub-center is the greatest among all stations, thus contributing to the city-level strategy to expand to the east.





2. Key Questions

Single station simulation

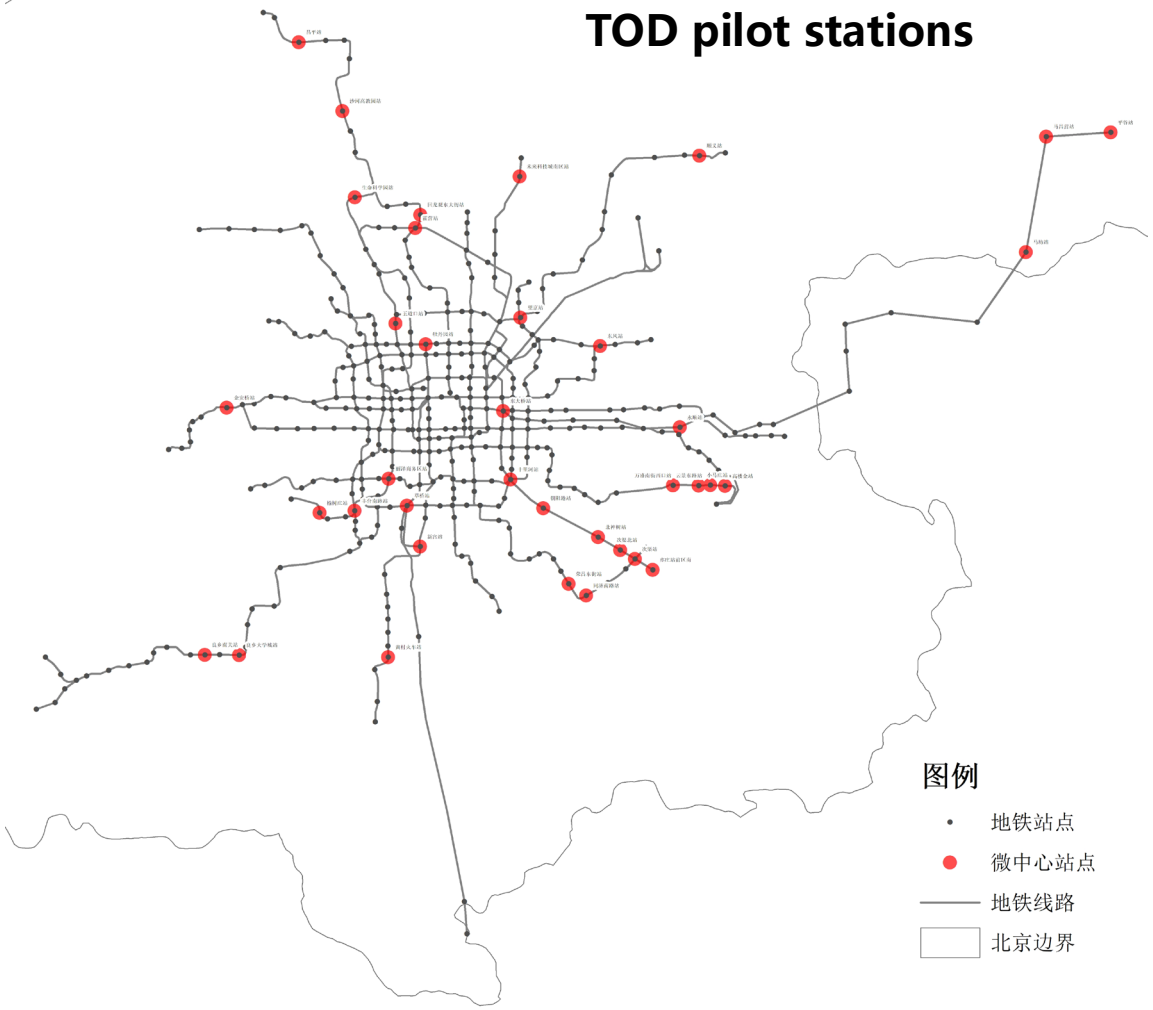
- 37 station sites which are suitable for development in the near future are selected by government as TOD pilot sites

S1：Baseline scenario

land use plan of Beijing 2035

S2：开发强度提升:
FAR increase
(FAR +10%, +30%, +50%, +100%, *pro rata* from Baseline)

S3：开发强度提升+就业优先:
FAR increase + job priority
(FAR +50%, additional business floorspace growth)



2. Key Questions

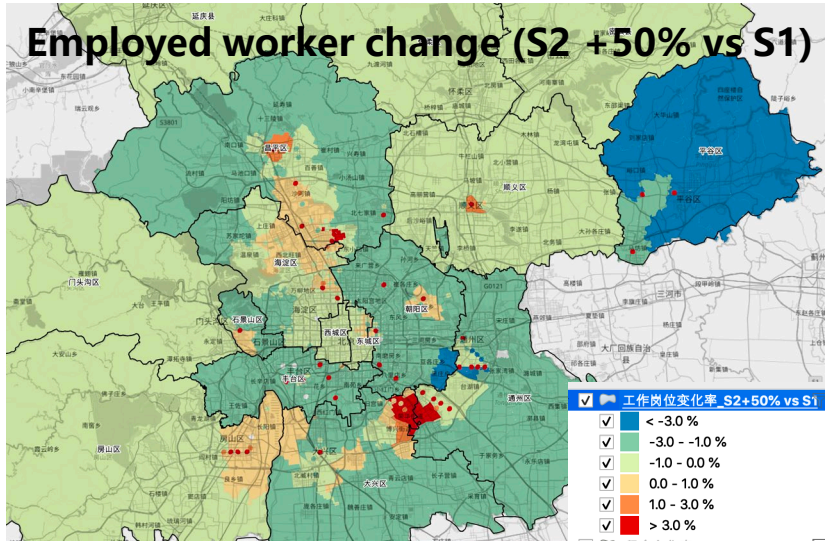
Single station simulation

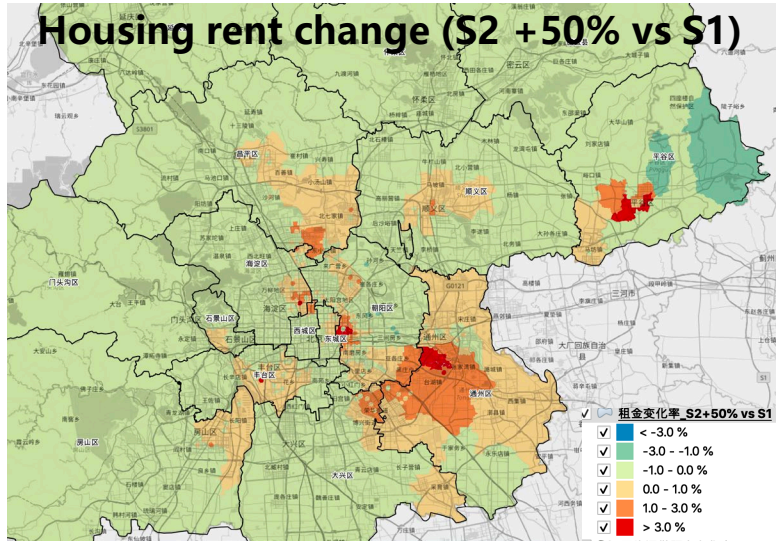
S2-Baseline : Investigate the effects of FAR boost at selected TOD pilot sites

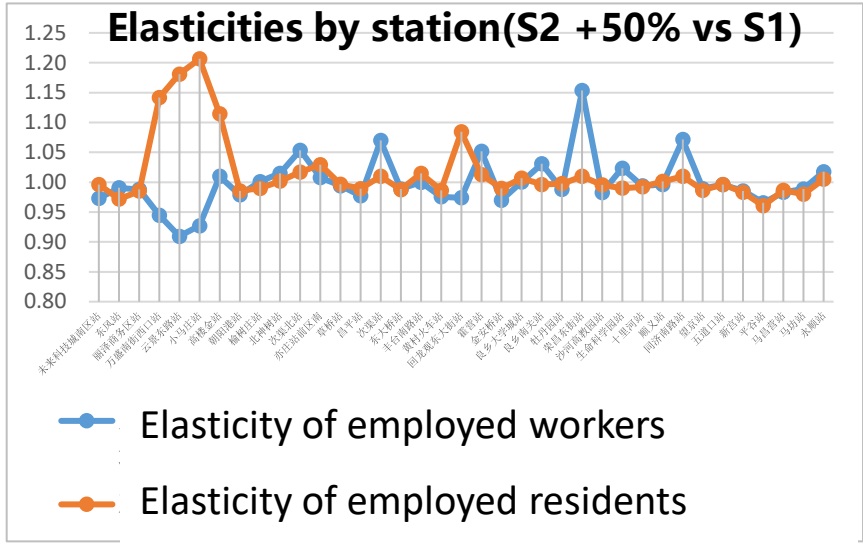
- FAR boost at pilot sites promotes the employment **growth in the immediate neighbors**, but would cause **displacement in other zones further away**.
- According to the location and social-economic situation, pilot station areas have different population and employment growth elasticities :
  - Employed workers: 0.91-1.15, Employed residents : 0.96-1.21

$$E_r = [(R_{s2} - R_{s1})/R_{s1}]/[(H_{s2} - H_{s1})/H_{s1}] \qquad E_j = [(J_{s2} - J_{s1})/J_{s1}]/[(B_{s2} - B_{s1})/B_{s1}]$$

E: elasticity, R: employed residents, J: jobs, H: housing floorspace, B: business floorspace, S1, S2: scenario Sa, S2







2. Key Questions

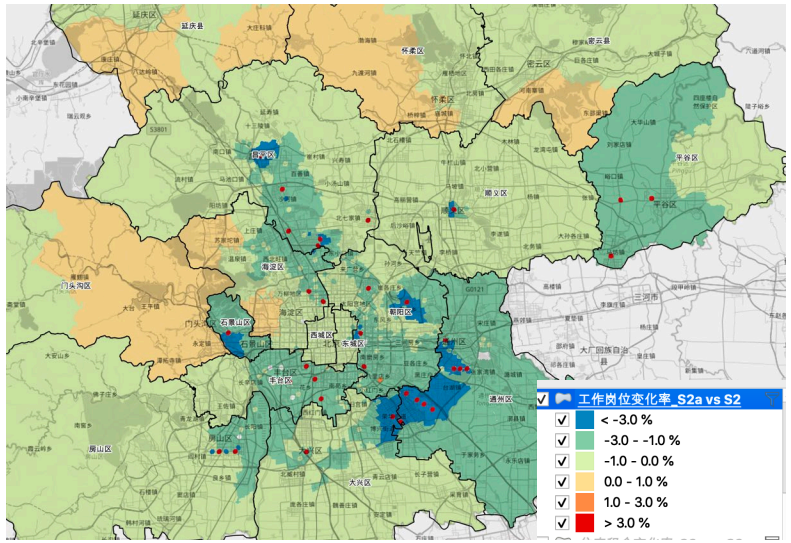
Single station simulation

S3-S2 : Investigate the effects of land-use change (employment-oriented) at selected TOD pilot sites

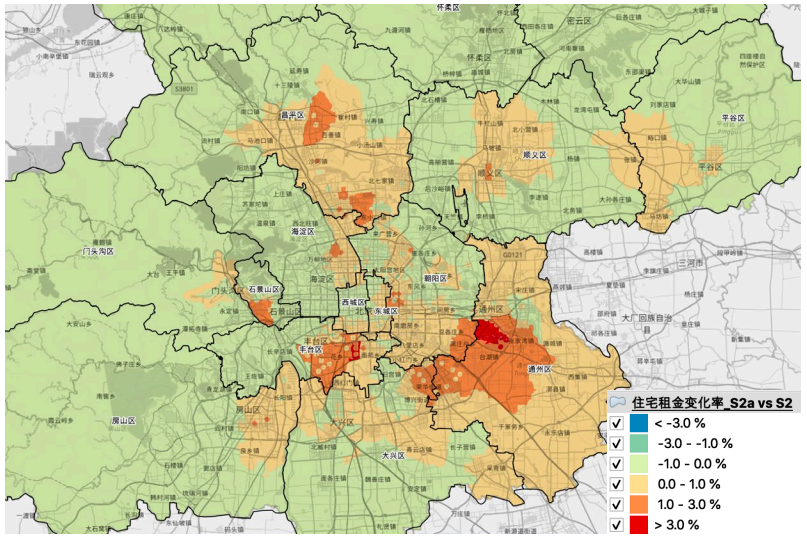
Increasing business floorspace provision at pilot sites (aggregate growth constant) will:

- attract employment from the surrounding areas;
- increase housing rent in the surrounding areas;
- Increase average commuting distance at pilot sites but reduce commuting distance for the neighboring areas.

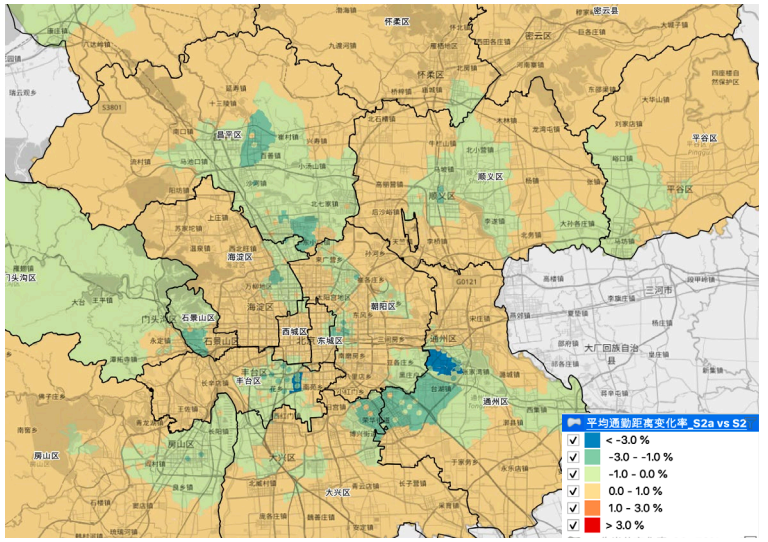
Employed worker change (S2a vs S2)



Housing rent change (S2a vs S2)



Commuting distance change (S2a vs S2)



2. Key Questions

2.4 Urban Form

根据情景模拟的结果，地铁站点周边地区毛容积率在规划情景的基础上上调20%-50%，即毛容积率达到1.2-1.4左右，相比2035年的基准规划情景，对于人口疏解、优化人口和岗位布局、缩短平均出行距离、提升土地价值，已经具有较显著的影响。

Model-based scenario analysis suggests that, a 20% - 50% gross FAR increase based on the Baseline in the station catchment areas (to achieve an average gross FAR 1.2-1.4) would have a significant impact to attract residents from the Central City, facilitating a transition towards polycentricity, shortening average local commuting distances, and boosting land value in the suburban areas.

毛容积率1.2-1.4的城市形态是什么样的?

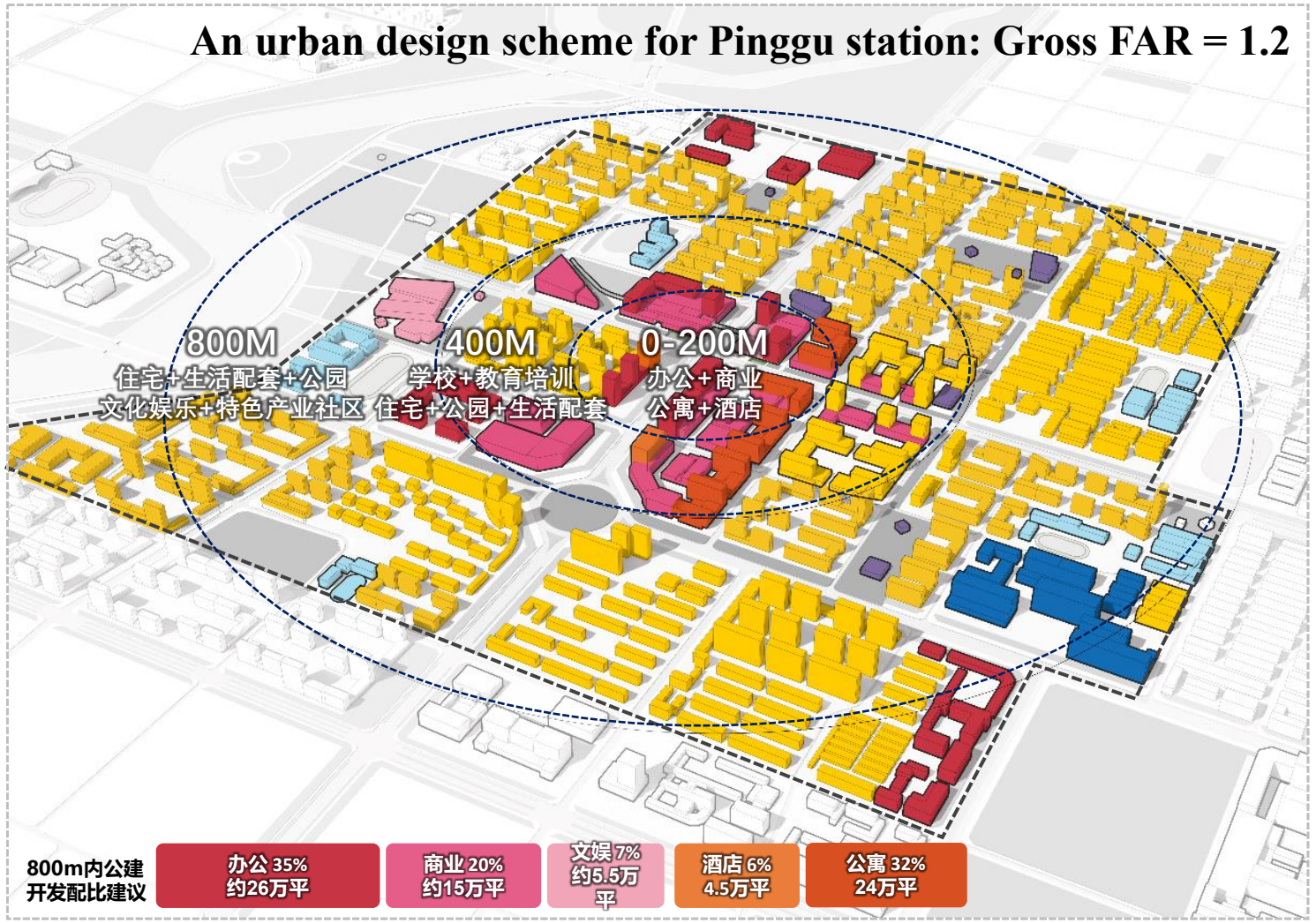
What does the urban form look like when the gross FAR is 1.2 to 1.4 in Beijing?

2. Key Questions

- **Gross FAR = 1.2, for a suburb station providing mainly residential services.**

平谷站概念设计：毛容积率约1.2

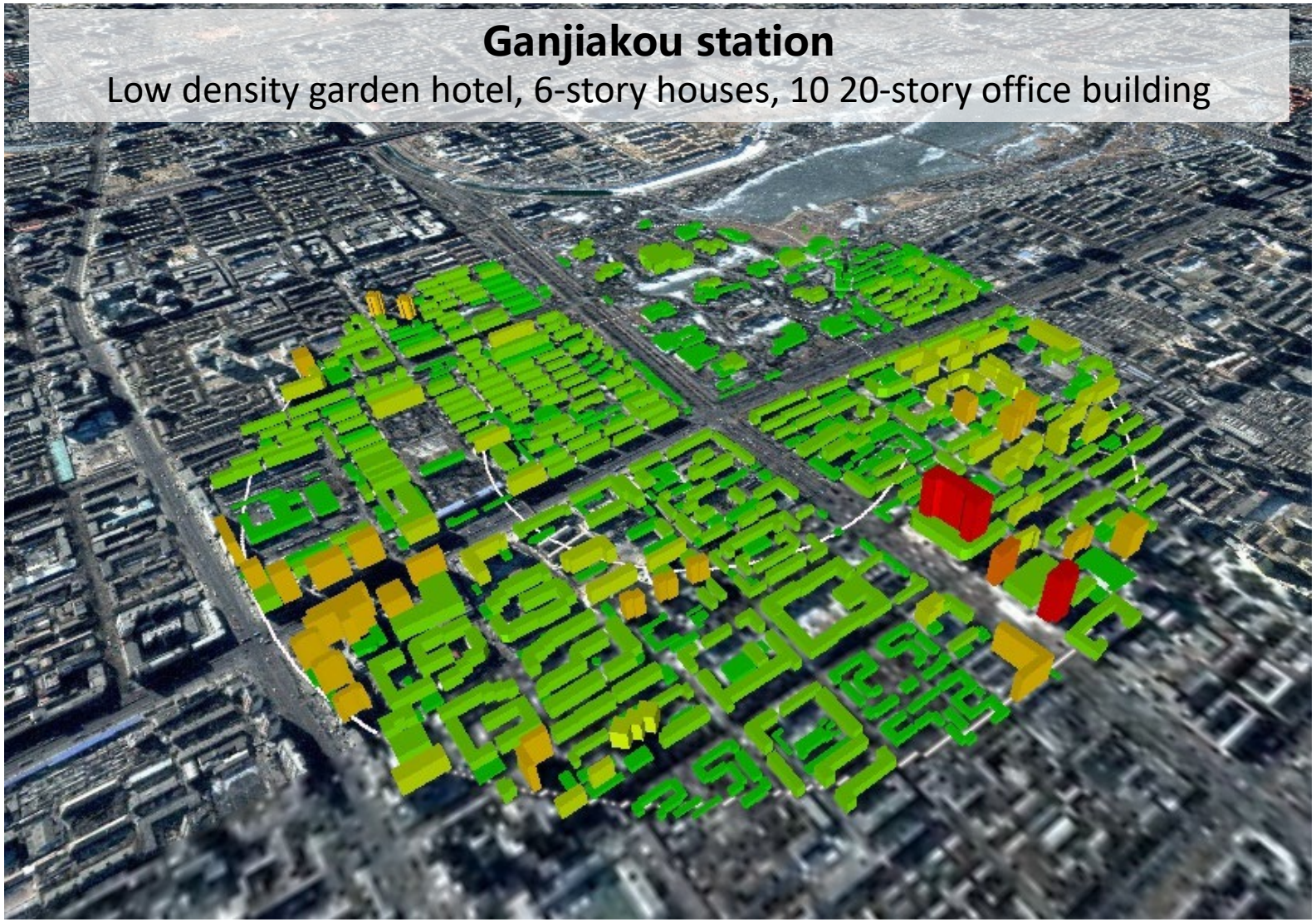
功能	占比	业态	体量(万平方米)
酒店	2%	商务酒店	4.5
公寓	11%	商务公寓	24
商业	7%	体验购物	11
		站前中央公园商业街	4
文娱	2%	文化娱乐公园	4.5
		文化体验展馆	1
办公	12%	甲级写字楼	14
		创业孵化花园	12
住宅及配套	66%	住宅	140.5
		配套(教育/医疗/文化)	4.5
合计			**220**



2. Key Questions

- Benchmarking: Ganjiakou Station area in central city of Beijing. Gross FAR=1.22

- Urban scene with gross FAR 1.2 will be acceptable.



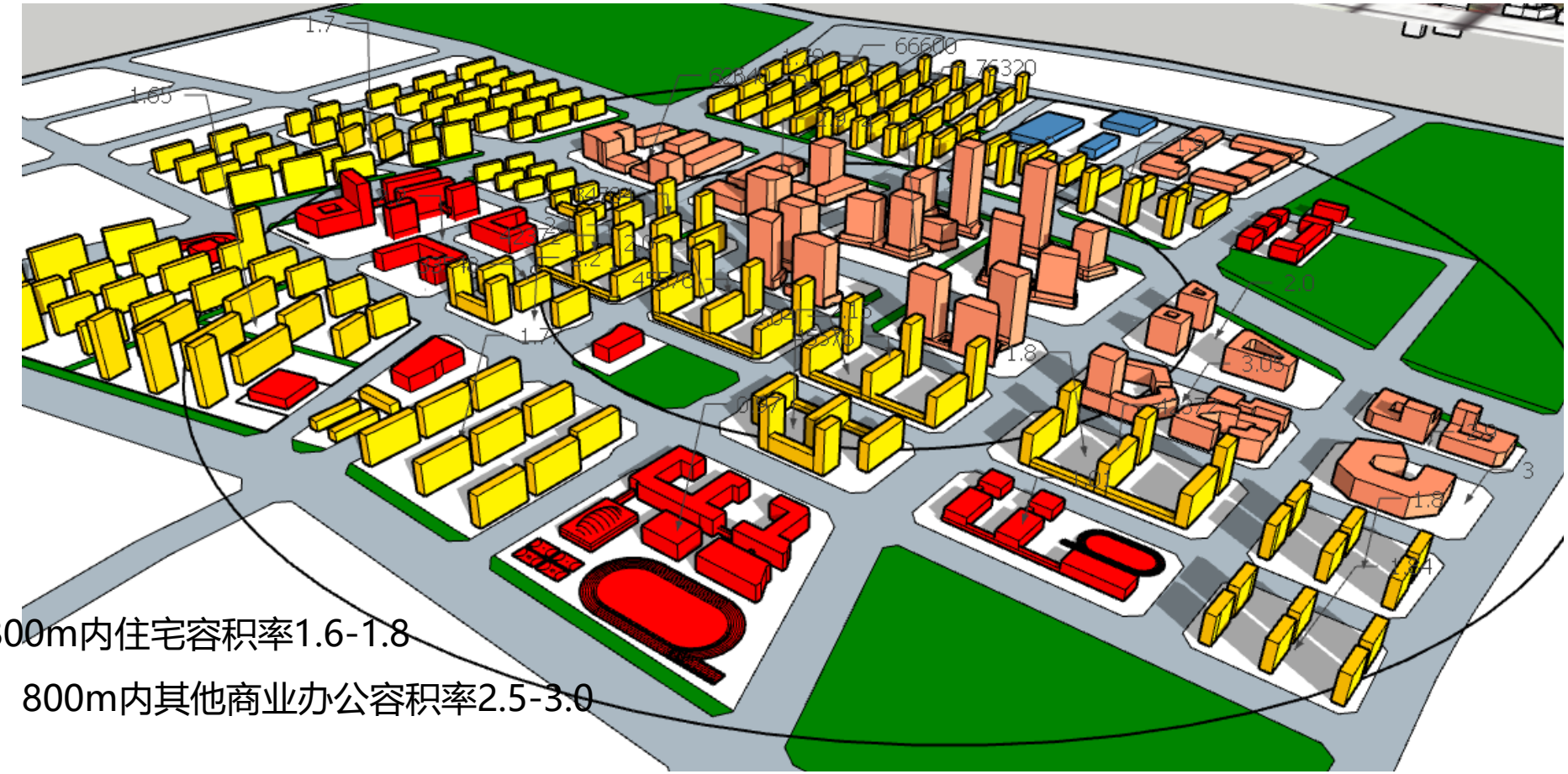
甘家口站

地类	建筑面积	用地面积	平均容积率	最大容积率
A	617046.3	647677.4	0.95	5.2
B	520001.2	158572.9	3.28	7.69
C	10746.69	12054.71	0.89	
G	1388.927	67434.38	0.02	
M	7621.309	6211.866	1.23	
R	1222332	699156.4	1.75	5.2
S	80331.79	64201.11	1.25	
U	905.0904	1078.965	0.84	
X	4149.167	20767.69	0.20	
总计	2464522	200960	1.22	

2. Key Questions

- **For a suburb station of the employment service type.**
- **Gross FAR = 1.4**

Urban design of Cigezhuang station as a sample

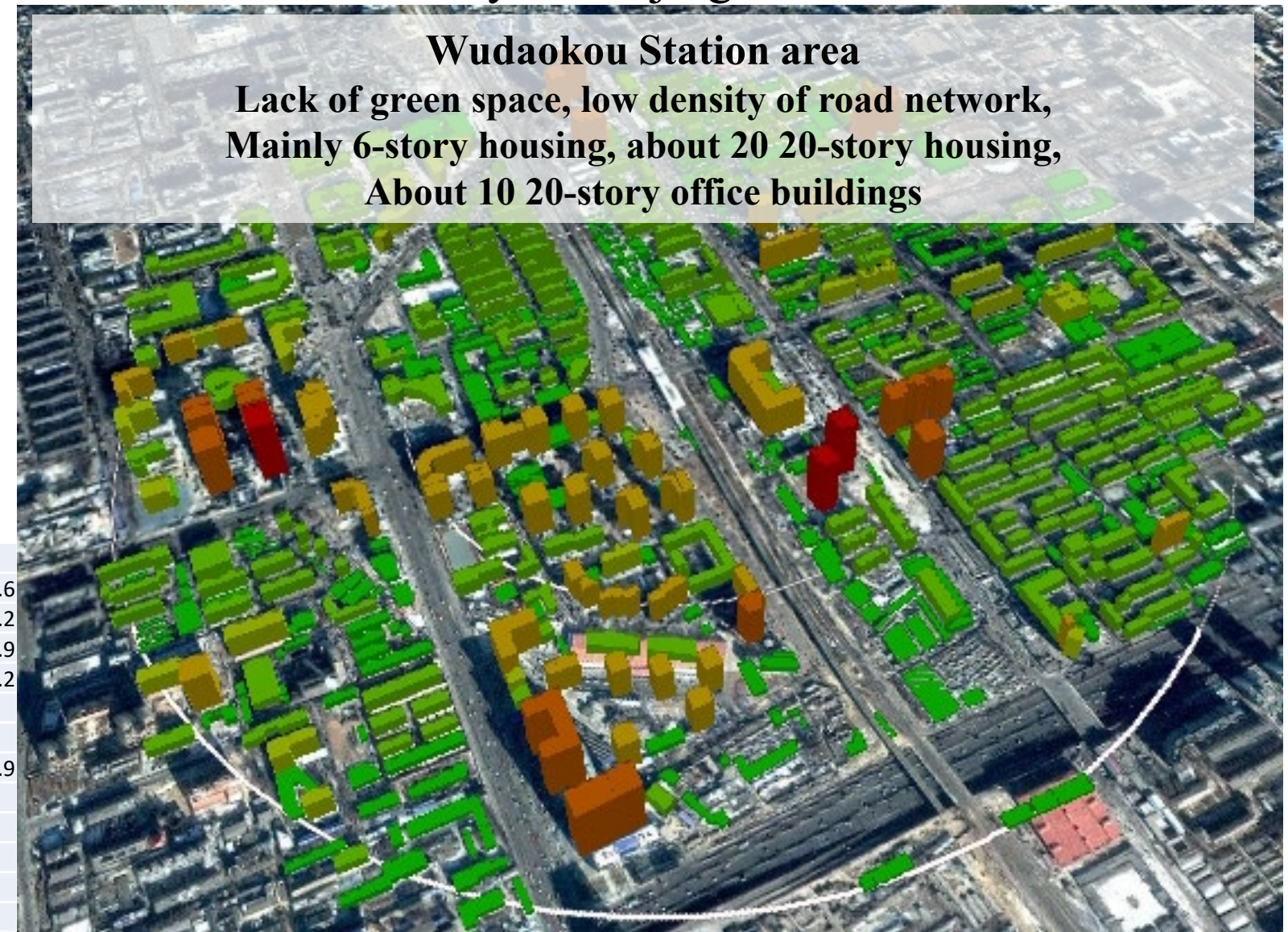


- 400m内住宅容积率2.0，400-800m内住宅容积率1.6-1.8
- 轨道站紧邻商业办公容积率4.0，800m内其他商业办公容积率2.5-3.0
- 学校1.0-1.2，医院1.6。

2. Key Questions

- Benchmarking: Wudaokou Station area in the Central City of Beijing. Gross FAR=1.6

- Urban scene with gross FAR 1.4 will be better than Wudaokou.



五道口站

地类	建筑面积	用地面积	平均容积率	最大容积率
A	1067618	626329.2	1.70	2.6
B	619992.2	178625.8	3.47	9.2
C	7083.862	13967.91	0.51	0.9
F	242886.3	49061.13	4.95	5.2
G	17020.04	71316.22	0.24	
M	47414.54	50842.87	0.93	
R	1369759	587444.5	2.33	3.9
S	1800.665	24604.98	0.07	
T	2584.618	54001.02	0.05	
U	33536.4	14001.53	2.40	
X	0	2629.852	0.00	
总计	3409695	2009600	1.69	

3. Conlusions (1)

Conclusions

- Recent mobile phone trace data shows that the main subway station catchment areas in Beijing range from 400m to 800m in radius.

- According to the Beijing-Tianjin-Hebei RSE Model simulations, concentrated and boosted floorspace growth around suburban subway stations can help relieve the population pressure in the Central City, promote the balance of jobs and housing, shorten local commuting distances along the subway lines, and improve the land values in the suburbs.

3. Conlusions (2)

- Beijing does not have to adopt an ultra-high-density strategy as Tokyo or Hong Kong, and should consider an appropriate density given its particular context and growth aspirations. For subway station catchment areas (800 meters radius), a gross FAR of 1.2-1.4 not only can improve the land-use and infrastructure efficiency and promote sustainable travel, but also achieve a higher quality and more attractive cityscape.

- It is expected that several suburban centers will emerge and mature in Beijing, the process of which may now be accelerated by the pandemic. An enhanced and tailored TOD strategy, together with efforts of reviving the tradition of low carbon travel (Beijing used to be a city of bicycles), can set up a new model for sustainability for cities facing similar development challenges in the developing world.

Thanks

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