The Impact of New Rail Stations on Rail Commuter Growth and Land Development

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Abstract

In the early stage of new urban rail lines opening, the increase in passenger flow (PF) is a key factor supporting the sustainable planning, construction, and management in Chinese cities. However, the initial passenger flow density (PFD) of some urban rail systems fails to meet the requirements of the State Council's Document No. 52, which calls for an average of 0.7 thousand PFD per day. One of the important reasons for the difficulty in increasing rail PFD is the weak aggregation of commuting populations around urban rail stations on the outskirt areas of cities, leading to slow increase or stagnation of PF. Previous studies are relatively limited on the spatial-temporal interaction between land use, population growth, and newly built rail stations & lines on the urban periphery, making it difficult to effectively support urban rail planning and PF growth for rail lines on the outskirt areas. This study analyzes the growth of commuter populations before and after the opening of rail stations in Shenzhen, China. By combining multi-year LBS commuting data, POI data, and rail station construction data, this study developed a Difference-in-Differences (DID) model to assess commuter population changes with respect to rail and land use changes. The results indicate that, compared to before the stations were opened, the new stations on the outskirts of Shenzhen between 2017 and 2022 have brought an 8.4% increase in commuter population. The commuter population and land intensity before station opening affect the population growth after station opening. Mixed and high-density land use, such as educational, cultural, residential, corporate, and transportation facilities, helps to concentrate the commuter population around rail stations. The proposed research framework and result help clarify the rail performance evaluation challenges faced in metropolitan planning in Chinese cities, supporting local governments and rail operators in achieving sustainable rail development.

Keywords: *transportation planning; rail transit; propensity score matching; difference-in-differences; land development; short-term; commuting population*

1. Introduction

Peripheral urban rail transit supports the city in terms of fast centripetal travel services and convenient connections to the same circles. Rail lines linking the center and the periphery and city-led suburban rail lines have become the focus of rail construction. However, rail construction requires a large amount of financial expenditure, and poorly located rail stations and lines make it difficult to realize the growth of the commuter population in the short term to drive the growth of passenger flow and the appreciation of land value, thus making it difficult to achieve a balanced income and expenditure for rail transportation. According to the State Council's Opinions on Further Strengthening the Planning and Construction Management of Urban Rail Transit (State Council [2018] No. 52)[1] and Guiding Opinions on Financial Support for Debt Risk Resolution of Financing Platforms (State Council [2023] No. 35)[2], along with the growing local financial pressure of debt bonding and the clear requirement to improve passenger flow, the investment in rail transit infrastructure in some cities has significantly The investment in rail transit infrastructure in some cities has been drastically reduced, and the construction has slowed down or stagnated. Urban rail transit companies need to rely on proven methods to assess the return on rail transit investment, such as land appreciation, rail passenger flow enhancement, and external benefits such as improvement of the human environment. The synergistic effectiveness of rail transit and land use is unclear, as scientifically sound land use allocation is a prerequisite for occupational and economic growth.

Compared with the study of rail and commuter population in the core range of the city, there are differences in the commuting characteristics, land development patterns, and transportation supply conditions of residents around the peripheral rail in the city. Zhao Hui et al [3], Sun Bindong et al [4], and Hao Yuan [5] found that the variability of the occupational and residential space in the city may cause differences in commuting characteristics. Yanwei Chai et al [6], Yuanyuan Xu et al [7], and Natural Zhang et al [8] found that as the spatial extent of the city grows, the commuting distance of residents appears to grow. Residents in peripheral areas of the city choose workplaces that have relatively low housing prices but can be reached more easily by rail transit. Tana et al. [9] found that residents located in the periphery of the city exhibited “spatial exclusion”, “localization”, “suburbanization”, “polarization” and “urbanization”. “and “urban dependence” and other diverse lifestyle characteristics. The functional configuration of the urban periphery needs to give full consideration to the needs of residents, and meet the basic needs of suburban residents and the need for quality improvement. Li Minggao et al [10] found that the difference in accessibility of rail stations has different impacts on the growth of commuter population. New rail stations with rail transit expanding to the periphery (rather than grid weaving), the occupational and residential scale of the peripheral range is affected by the land use (mixing degree and density), location (distance from the CBD), and location of the station (interchanging station, general station).

The land, population, and job impacts of rail station line openings oriented towards the immediate post-opening period are often overlooked in established studies.Billings et al. [11], Seo et al. [12] found that pre-opening of a rail station tends to bring about an increase in house prices because of the expected increase in transportation location. It is reasonable to speculate that homebuyers may have purchased a home prior to the opening of a rail station and moved in a short time after the opening of the rail station, becoming new residents around the rail station. The effect of public transportation on the land use and population size of an area has been proposed or observed in theories such as smart growth [13], TOD [14], and urban form [15] [16].Hurst [17] et al. found that the proximity of LRT to residential and industrial

land is more likely to lead to land use changes.Bhattacharjee et al. [18] found that after the opening of the railroad, commercial land use and residential community land use showed growth, and Credit [19] found growth in corporate businesses.Chatman et al [20] found that the proportion of transportation facilities such as parking that are rationed within and outside the service area of a rail station has a significant effect on the frequency and mode of regional commuting.

Differences in the base case of population and land use lead to a self-selection bias between rail station openings and population growth that requires further research. Rail station routes are more likely to be chosen to cover areas with concentrated population jobs, higher economic value, and faster growth, so the possibility exists that rail openings are indeed accompanied by population growth, however, this growth is not brought about by the rail. the study by Sanchez et al [21] also confirms that the effect of rail on job and residence is mixed. canales et al [22] found that rail routes are more tend to cascade into areas with already higher income jobs and types of jobs, and that these areas, rather than rail station openings, are responsible for further job growth. The impacts associated with rail station and land and population synergies can be unfolded based on well-established econometric methods, creating favorable conditions for research.Brown et al. [23] examined the socio-economic impacts of new rail station openings on a patch of neighborhoods using a General Linear Model (GLM), and Cervero et al. [24] examined the impacts of spatial, transportation facilities and services, household and community characteristics, personal characteristics, and other self-selectivity.

Based on the above issues and the review of related fields, this study proposes 2 hypotheses within the scope of influence of the newly opened rail stations in the peripheral expansion sites of our city:

1. The short-term commuter population will increase at a higher rate than outside the influence area.
2. Effective allocation of density and type of peripheral land contributes to the short-term commuter population increase.

2. Data and Methodology

2.1 Research Area

In this study, Shenzhen was selected as the scope of the study. The number of resident population in Shenzhen is more than 13 million and the GDP per capita is 203,000 yuan. The length of the rail line is at 316.1km. The study unit is a 250-meter square boundary of LBS data.

Tab. 1. Socioeconomic Information of the Study Cities (2019)

City Names	City Categories	City Resident Population (10,000)	GDP per capita (CYN)	Length of Rail Lines (km)
Shanghai	Megacity	2428.14	157300	809.9
Shenzhen	Megacity	1343.88	203489	316.1
Chengdu	Megacity	1658.10	103386	435.7
Xi'an	Megacity	1020.35	92256	158.0

2.2 Data Source

Relatively large sample and wide city coverage of new rail station data from 2019 to 2022. The rail station line information comes from the China Urban Rail Transportation Association's 2019 to 2022 yearbook, and the spatial information on rail line by and station layout comes from Internet maps. The spatial data is matched with the yearbook data to study all the information of the city since the first track was opened and operated until the beginning of 2023. From 2020 to 2022, Shenzhen City puts into operation 12 metro lines (excluding the guideway rubber wheel system) with a total mileage of 243.50 kilometers and 154 metro stations. The rail stations in different urban locations have significant differences in terms of travel accessibility and built environment, etc. In order to reduce spatial heterogeneity while focusing on the urban periphery (i.e., areas with potential for urban spatial expansion), this study screens out the newly built rail stations that are more than 10 kilometers away from the core functional areas of the city as the object of study.

Tab. 2. Opening Status of the Rail Stations from 2020 to 2022

City Names	Rail Name	Rail Length (km)	Opening Date	Numbers of Stations
Shenzhen	Line 6 Tier 1& Tier2	49.47	2020.08.18	27
	Line 10 Tier 1	29.31	2020.08.18	24
	Line 2 Tier 3	3.9	2020.10.28	3
	Line 3 South Extension	1.45	2020.10.28	1
	Line 4 North Extension	10.79	2020.10.28	8
	Line 8 Tier 1	12.34	2020.10.28	6
	Line 20 Tier 1	8.43	2021.12.28	5
	Line 14	50.34	2022.10.28	18
	Line 11 Fugang Interval	1.6	2022.10.28	1
	Line 12 Tier 1	40.54	2022.11.28	33
	Line 6 Tier 1	6.13	2022.11.28	4
	Line 16	29.2	2022.12.28	24

Internet location-based service (LBS) commute origin-destination (OD) data record the geographic location of the commute origin-destination link and the number of trips on a typical weekday throughout the year. Subject to data confidentiality and reliability requirements, the accuracy of the smallest research unit recorded by LBS data at this stage can reach 250 meters, and 250-meter accuracy is used in this study.The LBS data contains data from Shenzhen for four consecutive years from 2019 to 2022. According to publicly available travel data in Shenzhen, the starting point of commuting can be considered as the commuter's place of residence and the end point of commuting as the commuter's place of employment. Therefore, clustering the starting point of a commute at a 250-meter grid gives the commuter's residential end population in the area. According to the statistics of Shenzhen Transportation Bureau, the scale of commuting in Shenzhen is about 8 million times in a single day, and the sampling rate of commuting OD data in a single day is about 60%. Some scholars have tested the accuracy of Baidu urban population geography big data with the census results, which is basically consistent with the actual situation, and can more accurately reflect the spatial and temporal distribution pattern of the population. [25][26]

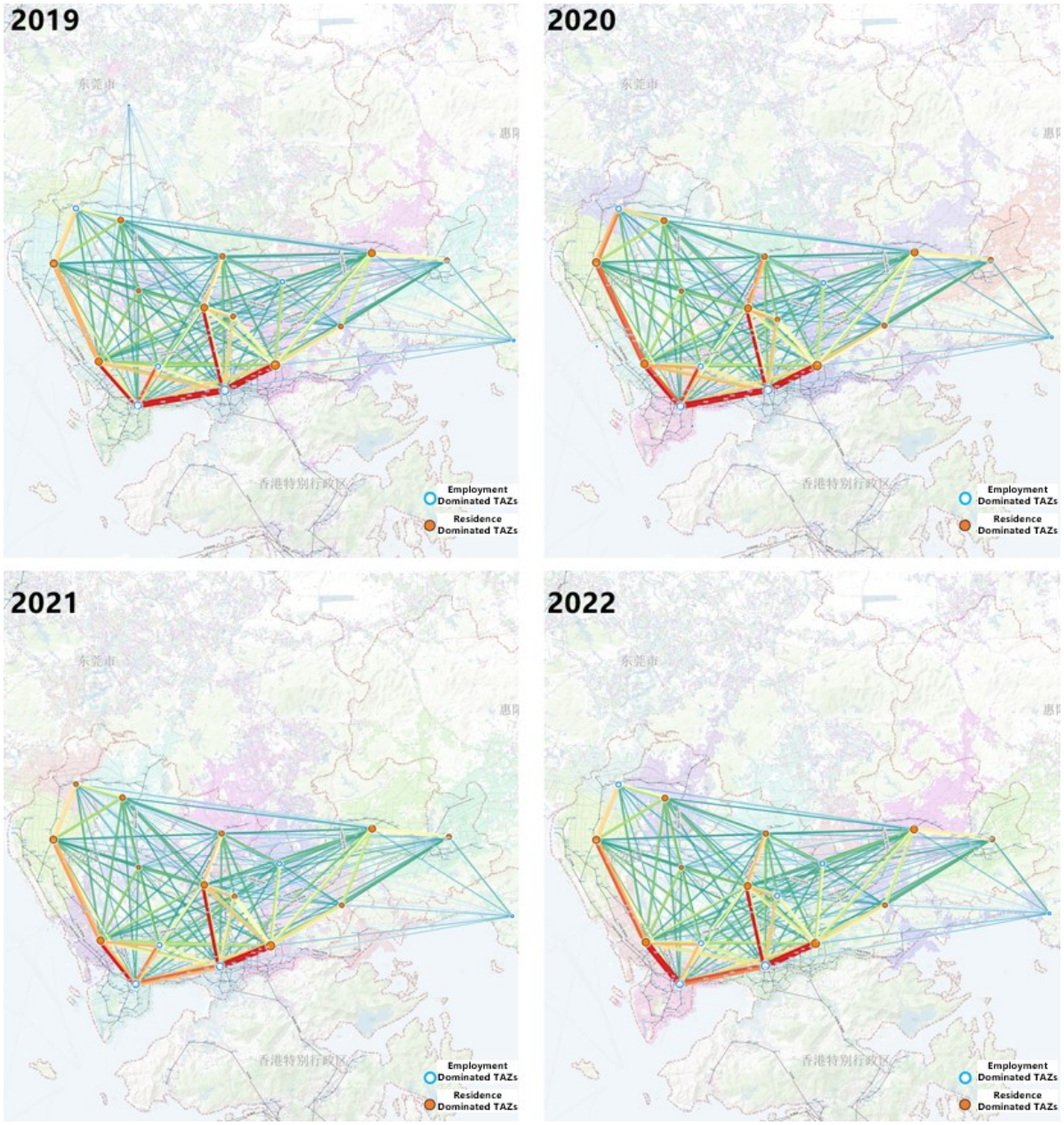

Fig. 1. LBS Commuting OD Data (The OD connection in this figure is a schematic representation, with feature explanations omitted.)

Internet electronic map point-of-interest (POI) data record information about various facilities and service points in the city. After cleaning and screening, a total of 12 categories of POI data are selected for this study, including transportation facilities, leisure and entertainment, companies and enterprises, healthcare, residential communities, automobile-related, living services, science, education and culture, shopping and consumption, hotels and accommodations, financial institutions, and catering and food. The data range from 2019 to 2022.

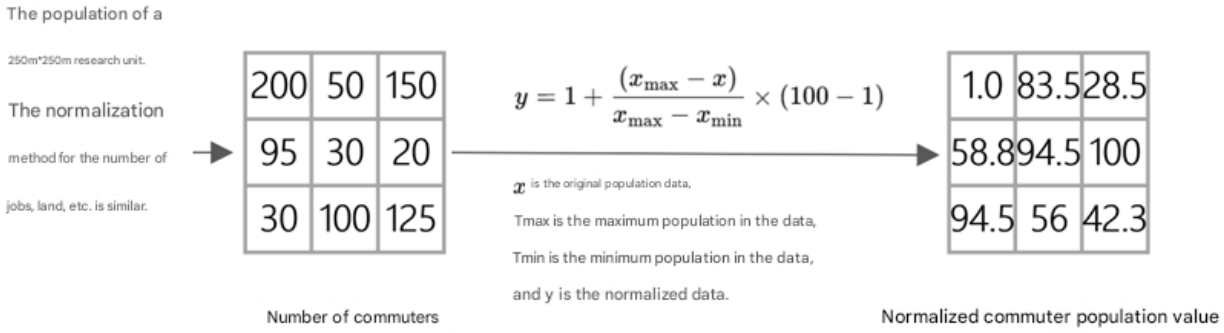

Fig. 2. The Illustration of Commuting Population, Employment, and POI Numbers Normalization Method

For commuting data and POI data, dimensionless 1~100 normalization is used to determine the normalization index value for the number

of commuting/POI categories in each raster according to the percentile ranking order among all rasters in the city, with 1 being the largest and 100 being the smallest. LBS data from different years may be affected by the sampling rate, and the absolute population values of the same raster in different years are not meaningful for comparison. In this study, the commuter population for each raster was converted to a percentile (Percentile) that compares to the commuter population for each raster in the city. A percentile of 0 means that the population of that raster is ranked highest in the city, and a percentile of 100 means that the population of that raster is ranked lowest in the city. Comparison of raster populations across years is accomplished in this manner. Similar to the commute OD data, this study converts the number of POIs for each raster to a percentile comparable to the number of POIs for each raster in the city. A percentile of 0 means that the raster has the highest ranked POI count in the city, and a percentile of 100 means that the raster has the lowest ranked POI count in the city. Comparison of raster POIs across years is accomplished in this manner.

2.3 Conceptual Framework

The opening and operation of rail line stations interact with land use and occupational and residential growth. This study selects the new rail stations in 2020 and 2021 as the research object, and analyzes the impact of the new rail stations on the commuting population in the periphery of the city, together with the commuting population and POI data of one year before and one year after the opening of the rail stations.

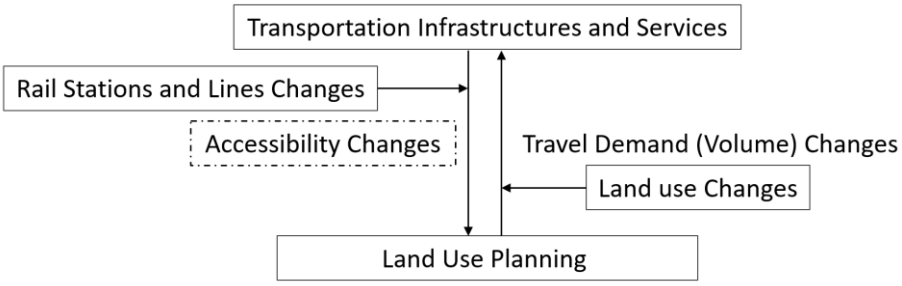

Fig. 3. LBS Commuting OD Data (The OD connection in this figure is a schematic representation, with feature explanations omitted)

In order to answer the interactive effects of rail station opening, land, and occupational and residential growth, the study is organized into three levels. First, this study compares the proportion of commuter population growth inside and outside the rail station's sphere of influence before and after the rail station opens to observe whether commuter population can be clustered around the rail station; second, this study incorporates the base year conditions of the station, land, and population into the comparisons to observe whether the clustering of commuter population around the rail station can be observed despite controlling for the above mentioned variables; and lastly, this study compares the situation of having population aggregation is compared by POI subcategories to observe the types and elasticities of POIs that enhance commuter population aggregation. The first two levels of the study design answer the first hypothesis described above, and the third level of the study design answers the second hypothesis described above.

2.4 Methodology

Step 1: Matching rasters

Using a threshold of a 10-minute walk from the rail site, the impact range for the rail site was determined to be 800 meters. To enhance the interpretability of the impact coefficients and the variability of the impact/non-impact ranges, this study spanned the interval from 800 meters to 1600 meters, and determined the non-impact range of the rail site to be from 1600 meters to 2400 meters. The geometric centroid of the commuter 250-meter study cell was within 800 meters of the rail site, i.e., it was labeled as a control group sample, and within the range of 1600 meters to 2400 meters of the rail site, i.e., it was labeled as a control sample.

The total number of OD samples for the matched rasters was 3613, covering 47 newly opened stations. Among them, the number of rasters within 800 meters is 1,575, and the number of rasters in the range of 800 meters to 1,600 meters is 2,038.

Tab. 3. Commute OD and POI Data Descriptive Statistics Results

Groups	Number of Rasters	Average of percentile change in commuter population before and after track opening [a]	Average of percentile commuter population before track opening	Average of percentile commuter population After track opening	Average of percentile number of POIs before track opening	Average of percentile number of POIs after track opening
Treatment（1）	1575	-0.427	17.751	16.421	13.039	11.892
Control（0）	2038	-3.523	30.765	29.264	18.986	16.614

[a] Note: negative values refer to rising rankings.

Fig. 4. The Study Rail Stations and Grid Areas (only selecting grids within the newly opened rail station areas in 2020 and 2021; treatment group samples are in red, control group samples are in blue)

Propensity score matching was used to match control and control rasters for the designated additional sites. Match data based on site density and mixing. Matching was done using the POI intensity and relative relationship of the rasters. The matching relationships were selected based on the principles of identical sites, similar commuter population size before opening, and similar POI intensity before opening. Considering that the accessibility advantage of interchange stations is obvious, and it is difficult to accurately define the type of new interchanges of existing stations, etc., and therefore the clustering effect on the population may be different from that of general stations, the study sample does not include interchange stations. This excludes differences in population growth due to differences in the scale of development in the sample, and also excludes differences in population growth due to differences in spatial location. For endogeneity due to changes in POI intensity over time, controls for POI intensity over time and grouping interaction terms are added in the second step.

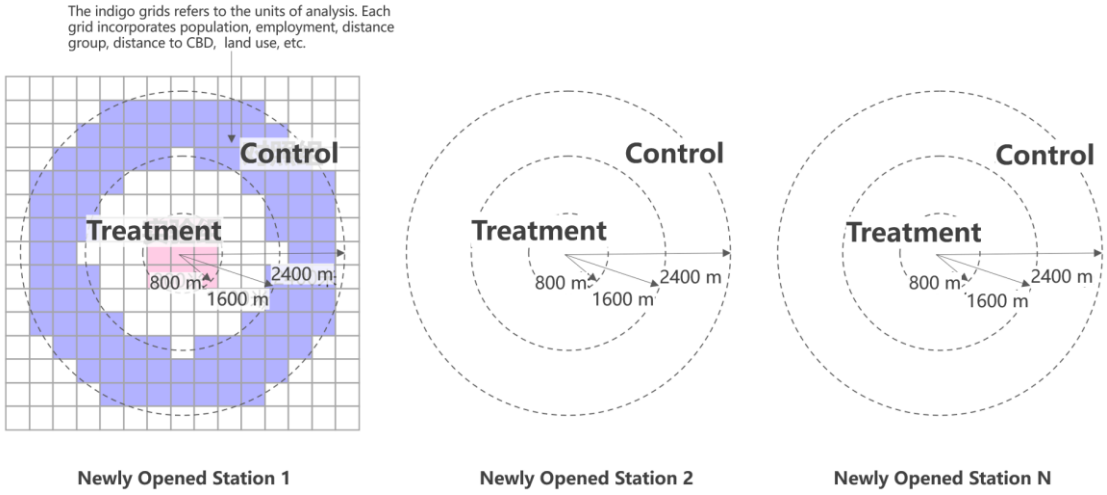

Fig. 5. The Illustration of Study Rail Stations and Samples (only selecting grids within the newly opened rail station areas in 2020 and 2021; treatment group samples are in pink, control group samples are in indigo

Step 2: Calculate whether rail opening increases commuter population

Perform OLS regression analysis (Eq. 1) on the original and matched samples in the sphere of influence and non-sphere of influence, respectively, and compare whether the significance indicators of the regression results change after matching the samples. If significance disappears, it indicates that the rail opening itself does not directly result in a population change, and that specific profiles of commuter population and POI need to be considered. If significance increases or decreases, it indicates that commuter population and POI can play a moderating role, and the population growth coefficients for the area of influence of the rail station are more accurate.

$$Popupctlchange_{ij} = \beta_0 + \beta_1 Group_{ij} + \varepsilon_{ij} \quad (1)$$

where Popupctlchange is the growth rate of the commuter population in a study unit 1 year before and after the opening of the track, with a maximum growth rate of 100% and a minimum growth rate of 0. {Group}_ is the sphere of influence of the newly opened track station, with 1 being within 800 meters and 0 being within 1600 meters to 2400 meters. i is the number of the commuter grid, and j is the number of the track station the grid belongs to .

Based on the matched samples, two control variables, pre-opening commuter population percentile and POI number percentile, are added to Eq. (1) to form Eq. (2). The addition of control variables tests the robustness of the matched OLS regression analysis and identifies the effects of the control variables on commuter population growth. In this study, the pre-opening population and the number of POIs are added to take into account, on the one hand, the fact that the growth of commuter population varies for sites with different development intensities

and population sizes. On the other hand, considering the lag in the impact of site functions and services, it is difficult for site changes in the year of rail opening or 1 year after rail opening to immediately affect the commuter population's relocation behaviour.

$$Popupctlchange_{ij} = \beta_0 + \beta_1 Group_{ij} + \beta_2 Popupctlbf_{ij} + \beta_3 Numpoiallpctlbf_{ij} + \varepsilon_{ij} \quad (2)$$

where Popupctlbf is the percentile of the commuter population 1 year before the opening of the rail station and Numpoiallpctlbf is the percentile of the number of POIs 1 year before the opening of the rail station. Other symbol meanings are consistent with equation (1).

Step 3: Judging the Impact of Subdivided Sites

For cities with significant results in the second step of equation (2), the key influencing factors that generate significance are further analyzed. Perform category splitting of pre-rail opening POIs, replacing the POI full category quantity percentile with the subdivision quantity percentile, and execute equation (3). Determine what site types play a significant role in influencing population enhancement around the site. Since a study unit with a high number of POIs in all categories may have a high number of POIs in each subcategory, the model was split into multiple models to avoid multicollinearity.

$$Popupctlchange_{ij} = \beta_0 + \beta_1 Group_{ij} + \beta_2 Popupctlbf_{ij} + \beta_3 Numpoiallpctlbf_{ij} + \varepsilon_{ij} \quad (3)$$

where Numpoisubpctlbf is the percentile of the number of POI subcategories 1 year prior to the opening of the rail site, with 0 being the maximum and 100 being the minimum.

3. Results

3.1 Influence of Overall Land Use Density

Table 4 presents the results of the effect of rail station opening on commuter growth considering the overall intensity of the site. For the case of unmatched control and control group samples (Model 1), Shenzhen exhibits significance, with a coefficient of -2.075 for the 800-meter range of a rail station that is likely to attract commuters. note that the negative value here suggests that the population within this range is elevated in the city compared to the other ranges. Matching the pre-opening population size and site intensity samples of the experimental and control groups (Model 2), the commuter population within 800 meters of a rail station increases by 8.1% compared to the pre-opening range compared to the range of 1,600 to 2,400 meters.

With the further addition of 2 control variables of population size and number of POIs before the opening of the station (Model 3), the population concentration in the 800 range of rail impacts in Shenzhen is still significantly higher than that in the range of 1600m to 2400m, and the growth rate of the commuter population in the 800-meter range of the rail station is about 8.413% compared to the pre-opening range of the station, which is an increase compared to Model (2). Meanwhile, the results of model (3) show that the commuter population base and the number of POIs before the opening of the station also affect the growth of commuter population. The more the commuter population before the opening of the station, the lower the population growth after the opening of the station (for every 1 position increase in the population size of the area before the opening of the station compared to other areas, the population growth after the opening of the station increases by 0.006%, i.e., from 8.413% to 8.413%). (i.e., from 8.413% to 8.419%, with other indicators explained in a similar way later in the article). As the population size grows, the potential for new population growth around the railroad tracks diminishes. In contrast, growth in the size of the POI before the station opens favors growth in the post-opening commuter population, with each 1-digit increase in the number of POIs bringing 0.007% post-opening population growth.

Tab. 4. The OLS Estimation Results (Dependent Variable: The Commuting Population Growth Rate Before and After Rail Opening %)

	Shenzhen		
	(1)	(2)	(3)
Dependent Varable	Percent growth in commuter population after rail opening %		
group = 1	3.075**	8.066***	8.413***
popupctlbf			0.006***
numpoiallpctl			-0.007***
Constant	-2.813***	-5.433***	-9.315***
Observations	3,613	1,608	1,608
R-squared	0.030	0.046	0.087

Note: Sig. *** p<0.01, ** p<0.05, * p<0.1

3.2 Influence of Subdivision Land Use Density

The results of the impact assessment of the POI segmentation types around the Shenzhen Railway show (Table 5) that the robustness test using the land use segmentation categories passes, and the propensity matching of the land use segmentation model is still based on the overall density of the land use in order to ensure that the conclusions are comparable and consecutive. Based on each site classification, the sample within 800 meters of rail stations still significantly concentrates the commuter population compared to the non-rail sphere of influence. The control variable base year population size still shows a significant negative correlation with population growth.

However, the growth in commuter population is characterized differently by the number of different site types. Among the 12 major types of sites, the larger the base number of POIs for transportation facilities, corporate, residential, science, education and culture, and shopping and consumption, the higher the increase in commuting population after the opening of the rail station. The highest increase is in science, education and culture, for every 1 digit advance in POI number, the increase in commuter population after the opening of the rail station increases by 0.006 digits. For every 1 position advance in the POI rankings of Residential, Corporate, Transportation, and Shopping & Consumption, the increase in commuter population increases by 0.005%, 0.005%, 0.004%, and 0.003%, respectively.

The types of businesses that could not increase commuter population growth include leisure and entertainment, healthcare, automotive-related, lifestyle services, shopping and consumption, financial institutions, and restaurants and food. It is important to note that the

configuration of these businesses, while not able to boost the commuter population, the effect on jobs or non-commuter population still needs to be determined by further research.

Tab. 5. OLS Estimation Results (Differentiated by Land Use Subgroups)

	Shenzhen											
Dependent Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**
	Percent growth in commuter population after rail opening %											
group = 1	8.186***	8.190***	8.609***	8.209***	8.086***	8.220***	8.240***	8.020***	8.286***	8.188***	8.211***	8.320***
popupctlbf	0.005***	0.004***	0.005***	0.004***	0.005***	0.004***	0.004***	0.004***	0.005***	0.004***	0.004***	0.005***
numpoitspipctl	-0.004***											
numpoientmpctl		-0.004										
numpoicomppctl			-0.005***									
numpoimedipctl				-0.003								
numpoihouspctl					-0.005***							
numpoiautopctl						-0.002						
numpoilifepctl							-0.001					
numpoicultpctl								-0.006*				
numpoicsmppctl									-0.003*			
numpoihotepctl										0.003		
numpoifinapctl											0.000	
numpoifoodpctl												0.003
Constant	-10.890***	-12.848***	-10.627***	-12.742***	-10.726***	-12.805***	-13.958***	-9.983***	-11.967***	-16.507***	-15.073***	-12.591***
Observations	1,608	1,608	1,608	1,608	1,608	1,608	1,608	1,608	1,608	1,608	1,608	1,608
R-squared	0.081	0.076	0.085	0.077	0.080	0.077	0.076	0.078	0.078	0.076	0.076	0.077

Note: t-statistics in parentheses, sig. *** p<0.01, ** p<0.05, * p<0.1

4. Conclusion

This study measures the impact of new rail stations on commuter population using PSM and OLS, as well as the role of land use intensity and the intensity of each sub-division of land use on commuter population enhancement. It is found that the newly opened rail stations in Shenzhen have a significant effect on commuter population enhancement. For rail stations expanding in the periphery of Shenzhen, the newly opened stations can bring about 8.4% of the commuter population growth within 800 meters of the rail stations in the same area. At the same time, the commuter population and land intensity base of the affected area before the rail station opens are different for the commuter population growth after the rail station opens. A larger commuter population base affects the magnitude of further population growth within the rail service area, while a larger site intensity base increases population growth. From the perspective of land use and service subcategories, the good allocation of science, education, culture, residential communities, companies, and transportation facilities plays an important role in the concentration of commuters around the railroad. Compared with previous studies, this study employs a higher precision (250-meter level) LBS data study unit, and also proposes a technical method for comparing LBS commuter ODs across time with repeated cross-section data. The adopted data and methodology underpin the identification and measurement of key influences on rail-land synergy.

The spatial expansion of cities needs to be supported by fast, high-capacity rail transportation. After experiencing rapid track mileage construction, economic and efficiency demands dictate that the country's rail is shifting from a construction-heavy approach to an operations- and service-heavy approach. The results of this study observe that the opening factor of rail stations, by itself, does not have a significant effect on the agglomeration of commuter population. Instead, the underlying conditions and land use, service allocation strategies and timing are important. The results of this study can provide a mechanism basis for the synergy between new rail stations and commuter population and land use at the metropolitan area level, and also provide a quantitative indicator value for the performance evaluation of rail stations on commuter population growth. At the same time, as the TOD concept has become an important strategy for the development of land around newly built railways in China's peripheral expansion areas, this study also provides quantitative index values for the impact of specific land development on population growth as a reference. Comprehensively improving the synergy between rail and land, continuously improving the theory and constructing the quantitative monitoring index system and toolkit will help the rail construction to form a good planning, construction, management and operation mechanism and support the development of China's cities.

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