The Crowding Out Effect of Subways on Buses

Botu Cai *

Department of Applied Statistics, Liaoning University, Shenyang, 110000, China

* Corresponding Author Email: 4032340191@smail.lnu.edu.cn

Abstract. In recent years, humanity's dependence on road traffic has been increasing, and the problems it brings have been growing, especially the issue of traffic congestion on roads, which has become increasingly prominent, and the "big city disease" and other issues have become more apparent. This paper uses the multi-time point difference-in-differences (DID) model to analyze the data of 285 cities in China from 1999 to 2021 and finds that the opening of subways has not significantly affected the passenger flow of buses, indicating that subways have not had a displacement effect on buses. The increase in subway passenger flow is mainly due to the change in residents' travel modes and may have an impact on other modes of transportation such as taxis and private cars. Therefore, for areas not covered by the subway, especially old communities with a large population, it is recommended to strengthen the public transport connection with subway stations and introduce new types of transportation such as micro-buses to improve the convenience of residents' travel. Building an integrated public transport system with rail transit as the backbone and regular buses as the network, where various modes of transportation work in synergy, is an inevitable trend in the development of major global cities and an important way to solve the traffic congestion problems in big cities.

Keywords: Subway opening; the multi-time point DID; transportation mode; bus passengers.

1. Introduction

As the city's size continues to expand and its economic level continues to improve, the construction of urban infrastructure plays a pivotal role in the economic and social development of the city. Urban rail transit is a new type of transportation mode, which plays a pivotal role in the development of cities. In recent years, with the acceleration of urbanization in the country, urban space has gradually extended from the central urban area to the suburban fringes, and the rapid development of cities has driven the rapid development of urban road traffic. Whether it's for work, study, or tourism, human daily life is inseparable from urban road traffic. However, due to the increasing dependence on road traffic, the problems it brings are also growing, especially the issue of traffic congestion on highways is becoming increasingly prominent.

The average annual subway passenger flow in the city is 607.8 million, and the bus passenger flow is 1.56 billion. The subway passenger flow accounts for 38.96% of the bus passenger flow, reaching 33.66% in 2018.This does not necessarily mean that the importance of the subway is declining. It is simply because the proportion of subway passenger flow in the cities where new subways are built is relatively small, leading to a decline in the overall level. There is a significant variation in the proportion across different cities. In Beijing and Shanghai, the subway passenger flow for the 0.1 percentile (urban population ranking in the top 10%) is 16.7 billion, and the bus passenger flow is 30.63 billion, with both ratios being over 50%. However, the research by Gonzalez-Navarro and Turner indicates that the proportion of subway passenger flow to bus passenger flow in major global cities is around 155%, while the proportion of subway to bus passenger flow in China is significantly lower than the average of other major cities internationally, suggesting that there is still tremendous potential for development in China's urban rail transit [1]. Additionally, in most cities, with the opening of subways, their passenger flow has shown an increasing trend year by year, while the number of bus passengers has shown an uncertain downward trend.

Research on subways mainly focuses on the following aspects: the relationship between subways and surrounding real estate prices: Diao utilized Singapore's newly constructed circular rail transit system and found that the opening of the rail transit led to an 8.6% increase in residential housing prices within a 0.6-kilometer radius of the rail transit stations [2]. Li found that the housing prices in neighborhoods with access to more job opportunities via subway are higher than in neighborhoods where subway access is not available [3]. The impact of subways on the urban environment: Chen demonstrated that after the construction of new railways in Taipei City, the emission of CO in motor vehicle exhaust decreased by 5-15% [4]. Li found that from 2008 to 2016, for every one standard deviation increase in subway density in Beijing, there was a 2% improvement in air quality [5]. The influence of subways on the urban economy: Datt and Ravallion believed that infrastructure has an important impact on economic growth [6]. Pradhan and Bagchi demonstrated in their study on the impact of infrastructure on economic growth in India that there is a unidirectional causal relationship between rail transit and economic growth [7]. And the role of subways in improving transportation accessibility: Yang showed in his research that the construction of six new rail transit lines in Beijing from 2009 to 2015 alleviated urban road traffic congestion in a relatively short period of time [8]. However, fewer scholars have paid attention to the relationship between subways and other modes of transportation. In the limited research on the impact of subways on bus passenger flow, scholars around the world have different conclusions.

On the one hand, Yang used the natural experiment of Beijing's subway expansion and studied the impact of subway opening on traffic congestion through regression discontinuity design. The study found that the opening of subway lines significantly reduced traffic congestion, with an average reduction of 15% in delay time. This may indirectly suggest that, due to the subway providing a faster mode of transportation, some passengers who originally took the bus switched to the subway, thereby reducing the passenger flow on buses [8]. Liu and Li discovered every new subway line put into operation annually diverts about 4.1 percent of bus passengers, which is equivalent to saving at least 10 bus lines [9]. Kang used a questionnaire survey method to analyze the impact of the opening of Urumqi Metro Line 1 on the number of buses, routes, and passenger volume. The research results showed that the number of buses along the subway line increased and decreased [10]. Li stated that buses are the main competitive mode of transportation to rail transit. When the travel time of the former increases by 50%, the share rate of the latter will increase by 6.8% [11].

On the other hand, Gonzalez-Navarro and Turner conducted a study on the relationship between the extent of urban metro networks, population, and their spatial configuration. Among the 632 largest cities globally, the research found that a 10% increase in the metro range leads to an approximate 6% increase in metro passenger flow, with no impact on bus passenger flow. This suggests that the expansion of the metro network may have caused some passengers who originally took the bus to switch to the metro, thus reducing the passenger flow of buses [1]. Xiao found that the extension of the subway led to a significant increase in subway passenger flow, and the increase in passenger flow mainly came from the substitution of other modes of transportation by the subway [12].

In summary, there are two perspectives regarding the impact of subways on buses: one suggests that the former has an impact on the latter, while the other suggests no impact. In terms of research subjects, the aforementioned studies focus on major cities around the world, individual cities, or specific subway lines. This article will conduct research starting from 285 cities in China, making the sample more comprehensive. In terms of research methodology, previous researchers have utilized questionnaire surveys, Regression Discontinuity Design, and two-stage least squares methods. Unlike other studies, this article will employ the difference in difference (DID) model, treating the opening of subways as a quasi-natural experiment, constructing a DID variable to analyze the impact of the opening of subways.

2. Methodology

2.1. Data Source

The passenger flow data of buses (including urban trams) in 285 cities all come from the annual "China City Statistical Yearbook". The data on the opening time of subways in various cities was manually collected from urban subway websites, past years "Urban Rail Transit Statistics and

Analysis Reports" and Baidu Baike. The data on subway and bus passenger flows is as follows (Table 1). All control variables are sourced from the annual urban statistical yearbooks.

Table 1. Public Transportation Passenger Flow.

Passenger Flows	Sample Mean	0.1th Percentile	0.25th Percentile	0.5th Percentile	0.75th Percentile
Subway (100 million person-trips)	6.078	0.116	6.667	8.426	6.661
Bus (100 million person-trips)	15.600	30.632	23.192	19.318	16.786
Subway vs. Bus Ratio	0.3896	0.5441	0.4862	0.4362	0.3968

2.2. Model Selection

Considering the opening of the subway as a quasi-natural experiment, this paper explores the impact of the subway opening event on urban bus passenger volume based on a multi-period difference-in-differences (DID) model. Since different cities have different subway opening times, this paper opts for a multi-period DID approach. Cities that have opened subways are treated as the treatment group, while those that have not are considered the control group. This paper analyzed panel data from 285 cities over the period from 1999 to 2021. The specific model design is as follows

$$\mathrm{E_{i,t}} = \alpha_0 + \beta_1 \mathrm{did_{i,t}} + \beta_2 \mathrm{X_{i,t}} + \mathrm{u_i} + \mathrm{v_t} + \varepsilon_{\mathrm{i,t}} \tag{1}$$

$\mathrm{E_{i,t}}$ is the dependent variable, representing the bus passenger volume in the i-th city in year t. $\mathrm{did_{i,t}}$ is a dummy variable for the subway opening event; it takes the value of 1 if the i-th city has opened a subway in year t, and t is not less than the opening time, otherwise it takes the value of 0. β_1 is the coefficient of $\mathrm{did_{i,t}}$, which is used to measure the impact of the subway opening event on the bus passenger volume in the city. $\mathrm{X_{i,t}}$ represents a set of control variables that affect the bus passenger volume in the i-th city in year t. $\mathrm{u_i}$ is the city fixed effect, $\mathrm{v_t}$ is the year fixed effect, and $\varepsilon_{\mathrm{i,t}}$ is the random disturbance term.

2.3. Variable Description

Dependent variable is the bus passenger volume in the i-th city in year t. Independent variable is a dummy variable for the subway opening event; it takes the value of 1 if the i-th city has opened a subway in year t, and t is not less than the opening time, otherwise it takes the value of 0.

The introduction of all control variables is as follows. Gross Domestic Product (GDP), as a vital indicator in development economics reflecting regional economic strength and development status, is an essential material basis for cities to ensure per capita income and living standards of residents. It comprehensively considers factors such as economic output and population size to evaluate and assess the level of urban development and management, and to measure the level and quality of urban economic development. Existing research has shown that the higher the economic development level of a city, the stronger its attractiveness to labor force. Given its large base value, logarithmic transformation is applied to the GDP.

Cities with a higher degree of openness (OPEN) can attract more industrial investment and create more job opportunities, thereby affecting the construction of basic transportation infrastructure. In this paper, the ratio of the actual amount of utilized foreign capital to GDP is used to represent openness, with the amount of foreign capital converted into RMB using the year-end exchange rate.

Land (LAN) is an important resource endowment for cities and directly affects the population carrying capacity of cities. In this paper, the ratio of the built-up area within the urban district to the total administrative area is used to reflect the condition of urban land resources.

Cities with abundant educational (EDU) resources can attract more young people, enhancing the potential for urban population growth. As the population increases, it will have an impact on bus passenger traffic. In this paper, the proportion of educational expenditure in total fiscal expenditure is used as a proxy variable for urban educational resources.

The level of medical (MED) and health services reflects a city's public service capacity and livability, which is an important factor affecting population migration. After the population increases, it will have an impact on bus passenger traffic. The number of hospital beds per capita (per 10,000 people) = the number of beds per 10,000 people.

Industrial Structure (IS), Represented by the ratio of the output value of the secondary industry to the tertiary industry, a higher value indicates that the secondary industry of the city is relatively more developed. The employment absorption capacity, location, and transportation requirements of the secondary and tertiary industries differ, and the industrial structure may affect the city's scale and the construction of the subway system.

Fiscal Spending (FS) reflects the intervention effect of the government on urban development, which is represented by the proportion of urban public fiscal expenditure in the regional gross domestic product.

3. Results and Discussion

3.1. Baseline Regression

The baseline regression results of the impact of subway opening on bus passenger flow are shown in Table 2. From the results, the coefficient of DID is negative and not significant, indicating that the opening of the subway has not had a displacement effect on bus passenger flow. The adjusted R-squared value of the regression model is above 0.8, indicating that the regression model selected in this paper has a high degree of fit.

Table 2. Public Transportation Passenger Flow.

	estimated coefficient	standard error
did	-0.0935	(0.0668)
lnGDP	0.349***	(0.101)
IS	-0.0221	(0.0356)
OPEN	0.233	(0.741)
LAN	-0.115	(0.230)
EDU	-1.324*	(0.523)
MED	-0.00156	(0.00272)
FS	0.114	(0.254)
_cons	5.660***	(1.039)
Individual Fixed Effects	YES	
Time Fixed Effects	YES	
N	4225	
R^2	0.899	
Adj. R^2	0.891	

3.2. Parallel Trends Test

It is well known that when using the difference-in-differences (DID) method for empirical analysis, one of the important prerequisites is to pass the parallel trends test. This test verifies that the treatment group, which has not been affected by policy intervention, should have the same time trend as the control group. This is the so-called "parallel trend" assumption or "common trend" assumption. Therefore, this study needs to test for systematic differences between different cities before conducting the DID analysis to further verify the robustness of the results and conduct a parallel trends test. The following model is set up in this paper.

$$E_{i,t} = \alpha_0 + \sum_{s=-6}^{6} \beta_1 D_s + \beta_2 X_{i,t} + u_i + v_t + \varepsilon_{i,t} \tag{2}$$

This paper introduces a dummy variable D for the year when the subway was opened. When s > 0, it indicates s years after the subway opening; when s = 0, it indicates the year of subway opening; when s < 0, it indicates s years before the subway opening. In terms of the results of the parallel trends test chart, all the estimated values of the regression coefficients before the opening of the subway are not significant, which satisfies the parallel trends assumption of DID. In the year of the policy implementation and subsequent years, the estimated values of the coefficients are still not significant, which also indicates that the main regression results are reliable, and the opening of the subway has not significantly affected the total passenger flow of the bus (Figure 1).

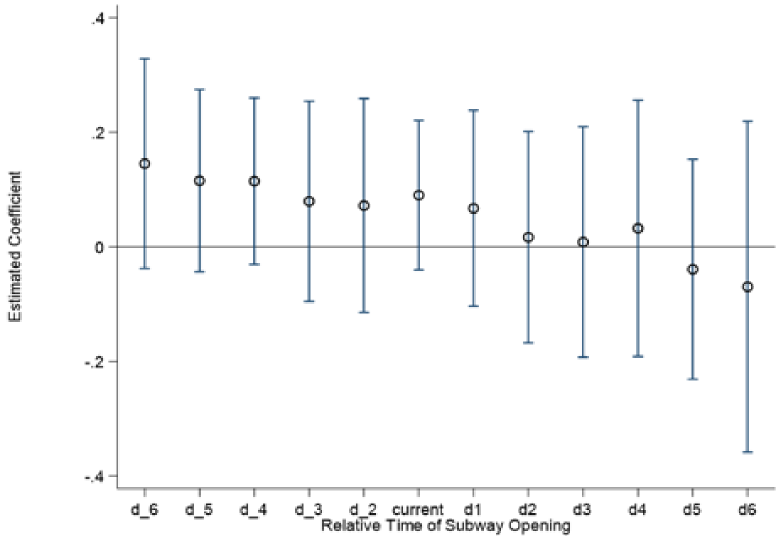

Fig 1. Parallel Trends Test.

3.3. Placebo Test

The placebo test in this paper is conducted by randomly creating fake treatment and control groups multiple times. Considering that other policies or unobserved events and other unobserved omitted variables may interfere with the results of subway opening affecting bus passenger flow. Stata 17 software is used to randomly select 46 cities out of 285 city samples as a fake treatment group, keeping other conditions unchanged, and then regression is performed again, repeating the above operation 500 times to obtain Figure 2.

From the figure 2, it can be seen that the regression coefficients follow a normal distribution and are mainly distributed around the value of 0. The P-values mainly fall between -0.07 and 0.07, indicating that most regression results would not be significant under random circumstances. The actual regression coefficient in this paper is -0.0935, represented by a dashed line in the figure 2, which is a certain distance away from the edge of the false regression, indicating that the result is not randomly generated but produced by the policy impact, and the conclusion is reliable. Therefore, the main regression result passes the test and has good robustness.

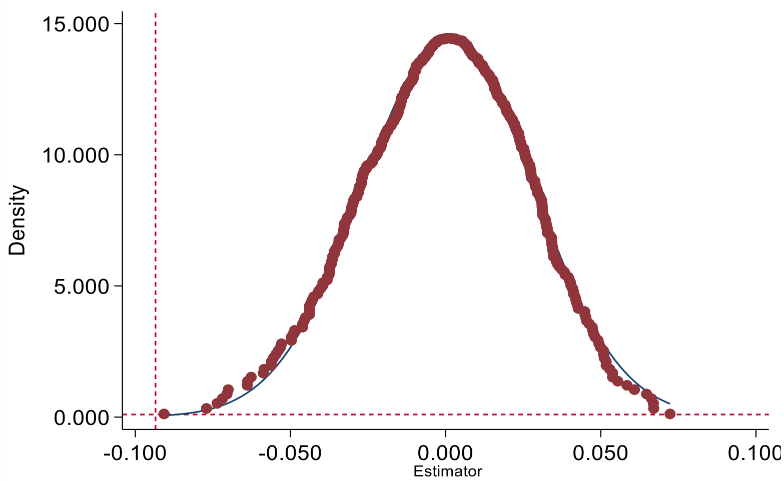

Fig 2. Placebo Test.

4. Conclusion

The expansion of subway scale has no significant effect on the passenger flow of urban buses, and the proportion of subway passengers in the total urban traffic is not high. During the sample period, the average annual growth rate of population in all subway cities is 1.35%, which is much lower than the average annual growth rate of urban bus passenger flow, which is 4.52%. The increase in subway passenger flow after its opening mainly comes from the change in residents' travel modes.

While the subway increases its own passenger flow without having a displacement effect on the bus passenger flow, it is bound to encroach on the demand for taxis or private cars and other modes of transportation. For old-style communities that are not covered by the subway and have a large population, it is necessary to improve the bus connections between them and the subway entrances, introduce new types of transportation such as micro-buses, and enhance the convenience of residents' travel. Building an integrated public transport system with rail transit as the backbone and regular buses as the network, where various modes of transportation work in synergy, is an inevitable trend in the development of major global cities and an important way to solve the traffic congestion problems in big cities.

References

[1] Marco Gonzalez-Navarro, Matthew A Turner. Subways and urban growth: Evidence from earth. Journal of Urban Economics, 2018, 108: 85-106.

[2] Mi Diao, Leonard Delon, Sing Tien Foo. Spatial-difference-in-differences models for impact of new mass rapid transit line on private housing values. Regional Science and Urban Economics, 2017, 67(1): 64-77.

[3] Li S, Chen L, Zhao P, et al. The impact of metro services on housing prices: A case study from beijing. Transportation, 2019, 46(4): 1291-1317.

[4] Whaley Chen. Green infrastructure: The effects of urban rail transit on air quality. American Economic Journal: Economic Policy, 2012, 4(1): 58-97.

[5] Ming Gao, Liqiang Chen, Shihong Guo. Urban rail transit and brt's impact on air quality: A perspective of urban heterogeneity. China Population, Resources and Environment, 2018, 28(6): 73-79.

[6] Datt G, Ravallion M. Why have some indian states done better than others at reducing rural poverty? Economica, 1998, 65(257): 17-38.

[7] Pradhan R P, Bagchi T P. Effect of transportation infrastructure on economic growth in india: the vecm approach. Research in Transportation Economics, 2013, 38(1): 139-148.

[8] Jun Yang, Shuai Chen, Ping Qin, Fangwen Lu, Antung A Liu. The effect of subway expansions on vehicle congestion: Evidence from beijing. Journal of Environmental Economics and Management, 20418, 88: 114-133.

[9] Changqing Liu, Lei Li. How do subways affect urban passenger transport modes?—evidence from china. Economics of Transportation, 2020, 23: 100181.

[10] Peiru Kang, Liang Hou, Yuxin Peng, et al. The impact of the opening of urumqi metro line 1 on the public transport market along the line. Urban Construction Theory Research, 2019, 13:145.

[11] Jinhai Li, Guanhua Yang, Yi Ding, Jianfeng Liu. The impact of new urban rail transit lines on travel mode choice. Transportation Systems Engineering and Information, 2022, 22(5): 135-140.

[12] Ting Xiao. The impact of subway development on urban population size and spatial distribution. Chinese Journal of Population Science, 2021, 1: 79-90.