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Cost of an urban rail ride: A nation-level analysis of ridership, capital costs and cost-effectiveness performance of urban rail transit projects in China

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Abstract: Although urban rain transit (URT) is an attractive alternative mode of daily travel, barriers exist in URT development across the world, in particular, the high cost of construction and operation and relative low rates of URT ridership. Despite these barriers, URT has gained considerable popularity worldwide in recent years; much of this trend is driven by projects in China. Despite this public support and implementation of URT projects, the ridership, capital costs and cost-effectiveness of URT projects remain largely unstudied. This paper addresses this planning and policy issue by examining line-level ridership and investment data for 97 heavy rail transit (HRT) lines and 12 light rail transit (LRT) lines in 28 Chinese cities. Comparative analysis is conducted so as to evaluate the performance and cost-effectiveness of HRT and LRT. Multiple linear regression analysis is used to explain the variability of URT cost-effectiveness and how it varies depending on land use density, project design, system service, and multimodal transit integration. Findings indicate that land-use density, line length, number of transfer stations, operation time, and bus ridership significantly contribute to higher levels of URT ridership, while URT ridership decreases significantly with train headway and the station's distance from the city center. It is cost-effective to develop URT in high-density cities in spite of high costs, and some, if not all, LRT lines are more cost-effective than HRT lines. As of this analysis, the overdevelopment of HRT in China has failed to plan for multimodal transport integration and operational optimization. However, these shortcomings are also opportunities for Chinese transportation and land-use planners to develop more cost-effective URT projects that also improve the level of service available to the public.

Keywords: Urban rail transit, cost-effectiveness analysis, land-use density, project design, system service, multimodal transport integration

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1 Introduction

Urban rail transit (URT) has experienced considerable development in the metropolitans across the world as an alternative mode of daily travel and a popular strategy to improve accessibility and mobility (Lee & Sener, 2017). Metropolitan transportation and land use planners regard the development of URT as an important strategy for accessibility gains (Lee & Sener, 2017), congestion mitigation (Shen, Chen, & Pan, 2016), greenhouse gas emissions reduction (Li & Song, 2016; Kelly & Zhu, 2016), and public health improvement (Sun, Webster, & Chiaradia, 2017). As of July 2017, more than 220 cities worldwide had implemented URT systems, with a total length exceeding 15,000 kilometers (Urbanrail, 2017). With dozens of cities having ambitious plans to extend existing URT projects, as well as others building new URT projects, investments in URT construction are expected to continue to rise in the foreseeable future.

Although URT is enjoying rapid development, barriers still exist. In particular, high costs and low ridership are significant barriers to overcome for URT investments (Guerra & Cervero, 2011; Sohu, 2015). Completed in 1972, the first post-WWII new-generation rail system in the United States cost $97 million per mile in 2009 dollars; comparatively, the extension of BART to the San Francisco International Airport completed in 2003 cost more than $180 million per mile (Guerra & Cervero, 2011). In Beijing, China, the adjusted capital costs per mile of HRT more than doubled from $110 million in 2000 to $250 million in 2015 (Sohu, 2015). While the potential value capture of these investments also comes from alternative means such as land value capture and urban attraction improvement (Cao & Ettema, 2014; Guerra & Cervero, 2011; Pacheco-Raguz. 2010; Ransom, 2018; Yan, Demelle, & Duncan, 2012), the ticket revenue from passengers is still one of the most important ways to justify the upfront investment in URT construction and operation.

The accuracy of cost and ridership projections have improved with the development of URT systems. However, experience of academics and practitioners alike suggests that cost-effectiveness analysis of URT projects is challenging and requires a thorough understanding the complexity of these megaprojects that have a variety of influencing factors (Pickrell, 1990; Webber, 1976; Zhao, Deng, Song, & Zhu, 2014). The impact of exogenous factors on URT cost-effectiveness, as well as how these mechanisms unfold and to what degree of impact, has not yet been fully understood. There are two plausible reasons. The first one is lack of data. A systematically analysis of the impact of one factor on cost-effectiveness is necessary to control for the influence of other factors. Thus, a certain sample size is needed. Only a few countries operate enough URT lines to provide such research context. Second, the importance of URT cost-effectiveness analysis has not been widely acknowledged, particularly by the emerging countries that have been developing URT ambitiously in recent years. However, a better understanding of URT cost-effectiveness performance and the influence of determinants on the performance would help improve service and accuracy cost-appraise projects.

China operates the longest running URT network in the world also with ambitious plans to construct additional URT lines. It is both possible and necessary to conduct a cost-effectiveness analysis in order to improve the performance of the existing systems as well as to guide new investment in the URT development. Thus, this research investigates the impact of factors measuring land use density, project design, system service, and multimodal transit integration on URT's cost-effectiveness performance. The data used in the study was collected through a national-wide survey on the existing URT projects in China. Daily weekday ridership information was matched with capital costs to produce capital costs per daily ridership. As a nation–level analysis, findings from this study would provide academics and practitioners with useful information on URT appraisal and development.

The remainder of this paper is organized as follows. Section 2 reviews and elaborates on previous research. Section 3 presents the study context and data sources. Section 4 introduces the analytical methodology. The results and findings are presented in Section 5. Finally, Section 6 discusses the findings and conclusions.

2 Literature review

Researchers and practitioners have long criticized the cost and ridership performance of URT projects as their actual capital costs usually exceed estimates, whilst ridership is systematically overestimated (Flyvbjerg, Holm, & Buhl, 2005; Kain, 1999; Pickrell, 1990; Webber, 1976). Auditors tended to explain these contrasts in terms of influencing factors and change orders outside of agencies' control; comparatively, academics have explained projection errors as strategic misrepresentations or lies (Siemiatycki, 2009). At a time when fiscal resources are shrinking and capital expenditures are soaring (Guerra & Cervero, 2011), understanding the impact of influencing factors on URT cost and ridership peris important for the sustainable development of URT systems.

However, successfully matching the influencing factors and cost-effectiveness performance is a great challenge. Research over the past decade has focused on the association between URT cost-effectiveness and various factors, such as the metropolitan economy, land use, system design, service features, multimodal transportation integration, and household and individual features, etc. (e.g., Arrington & Cervero, 2008; Ewing & Cervero, 2010; Guerra & Cervero, 2011; Ji, Fan, Ermagun, Cao, Wang, & Das, 2017; Taylor, Miller, Iseki, & Fink, 2009; Zhao & Li, 2017). Findings from these studies note that determinants of URT cost-effectiveness are often contextual and influence are both evident and yet difficult to isolate.

Macro-economic factors do affect the capital costs and usage of URT systems. Between 1972 and 2003, the cumulative inflation rate of the US dollar buying power was about 340% (U.S. Inflation Calculator, 2018); the adjusted cost of URT projects have more than doubled during the same period (Guerra & Cervero, 2011). Consumer economics theory suggests that the demand for a transit trip could be viewed as a function of both the utility of the trip and its costs (Ben-Akiva & Lerman, 1985; Train, 1993). Taylor et al. (2009) found that the metropolitan economy (specifically median household income) significantly impacted transit ridership. The elasticities of URT choice generally increased with gas price and decreased with transit fee (Shoup, 2005; Taylor et al., 2009). In Montreal, Zahabi, Miranda-Moreno, Patterson, & Barla (2012) observed an increase of 10 percent in the transit fee would reduce the mode split of transit by about 10 percent.

Several studies have discussed the relationship between land use and transit ridership (e.g., Ewing & Cervero, 2010; Kuby, Barranda, & Upchurch, 2004; Sohn & Shim, 2010; Padeiro, 2014; Tsai & Mulley, 2012; Zhao et al., 2014). These studies underlie the interdependent nature between land use and transit systems through which each supports and shapes the other. Findings indicate that land use and population density contribute to higher levels of transit ridership (Cervero & Kockelman, 1997; Kuby et al., 2004; Sohn & Shim, 2010). Cervero, Sarmiento, Jacoby, Gomez, & Neimen, (2009) found that land use mix, accessibility, and proximity to transit were associated with more physical activity and thus the potential in transit ridership.

In regards to population density, Kuby et al. (2004) found that employment and population were central factors in generating URT ridership. Meyer, Kain, & Wohl (1965) found that in high-density cities, rail tended to be more cost-effective than bus, whilst private cars were the least expensive travel alternative in low-density cities. Research from Pushkarev and Zupan (1977) indicates that net-residential population density of HRT investments was 12 households per acre, which was 1.3 times higher than that of LRT. Despite higher capital costs, investing in transit in higher density locations does tend to improve transit's cost effectiveness (Guerra & Cervero, 2011).

Transit service characteristics, measured by URT types (HRT or LRT), station types (above-ground or underground), and train headway, have also been shown to influence transit ridership (Arrington & Cervero, 2008; Kuby et al., 2004; Sohn & Shim, 2010; Zhao et al., 2014). Findings indicate that while LRT investments were touted as a low-cost alternative to HRT, LRT tended to be more expensive per ridership and per passenger mile on average in the United States (Guerra & Cervero, 2011). Above-ground stations generally attracted less ridership than underground stations as the later are usually located in downtowns with high densities rather than in suburban with low densities where above-ground stations are more commonly located (Zhao, Wang, & Deng, 2015). Train frequency and transit ridership showed an interdependent relationship through which each supports the other (Mohring, 1972).

Empirical studies have also quantified the effects of multimodal transport integration on transit ridership. The park-and-ride (P&R) facilities for cars and bikes as well as the integration of feeder bus lines around URT stations were found to be significantly and positively associated with URT ridership (Ji et al., 2017; Kuby et al., 2004; Sohn & Shim, 2010; Zhao & Li, 2017). In the United States, Kuby et al. (2004) found that each additional bus route increased LRT boardings on weekdays by 123, and each additional P&R space for car netted 0.77 boardings. For the dense city of Seoul, the estimated elasticities for bus route increases in HRT ridership ranged from 1350 to 1600 (Sohn & Shim, 2010). Pedestrian-oriented developments around rail stations also contribute to ridership and revenue of URT systems (Calimente, 2012). The presence of bike-sharing programs and bike P&R facilities around URT stations were associated with greater rates of bike-transit transfers (Ji et al., 2017; Zhao & Li, 2017; Zhao et al., 2014). Furthermore, transfer stations connecting two or more URT lines attracted more passengers than single-line stations (Kuby et al., 2004; Sohn & Shim, 2010; Zhao et al., 2014).

At the micro-economic level, individual-based studies examining the discrete choice behavior contribute an in-depth understanding of the influence of observed and unobserved factors on the relative attractiveness of each travel mode (e.g., Bowman & Ben-Akiva, 2001; Cao & Ettema, 2014; Cervero, 2007; Chatman, 2008; Noland & DiPetrillo, 2015; Zahabi et al., 2012). Findings generally indicate that transit cardholders with relatively low income and those from households owning no car or living near transit were more likely to use transit (Cervero, 2007; Shen et al. 2016; Noland & DiPetrillo. 2015). For a review of the disaggregate studies, see other such as Cervero and Day (2008), Creemers et al. (2012), Hess and Ong (2002), Nolan (2010), Prillwitz, Harms, and Lanzendorf (2006), Van Acker and Witlox (2010), etc.

In addition to these noted explanatory factors impacting URT ridership and capital costs, there are a variety of other observable and latent factors. These include historical and cultural factors that are unique to particular contexts. In this study, we focus on the impacts of factors measuring land-use density, project design, system service, and multimodal transit integration on URT cost-effectiveness performance at the line level in China. Given the importance of cost-effectiveness analysis as well as the rapid development of URT in China, more ridership and capital cost studies are likely to follow. This paper starts this exploration.

3 Study context and data sources

3.1 Study context

Over the past few decades, China has experienced rapid urbanization and motorization (Li, Song, & Chen, 2017). From 1971 to 2000, China's urbanization rate increased from 17.3% to 36.2%; by 2016 the rate had increased to 57.4% (NBSC, 2017). Corresponding to this growth, the number of privately owned passenger vehicles increased from 494,400 in 1971 to 16.1 million in 2000 and 194.4 million by 2016 (NBSC, 2017). This rapid urbanization and motorization in China presented a number of significant quality of life challenges, such as severe traffic congestion and intense air pollution (Shen et al., 2016; Kelly & Zhu, 2016).

In response to these challenges, the Chinese government has led global investment in URT systems. Since the first-generation URT system Beijing Metro Line 1 opened in 1971, Chinese investment in URT systems has continued to grow throughout the country. This growth in the URT network and investment the system began to surge in 2010 when the central government started to loosen its controls on URT development in response to widespread issues with congestion and air quality. By the end of 2016, URT systems, including HRT and LRT operated in twenty-eight cities, included more than 109 operational lines for a total length exceeding 3,610 km (Figure 1). With several dozen projects in planning and construction, the total length of China's URT lines is expected to exceed 6,000 km by 2020.

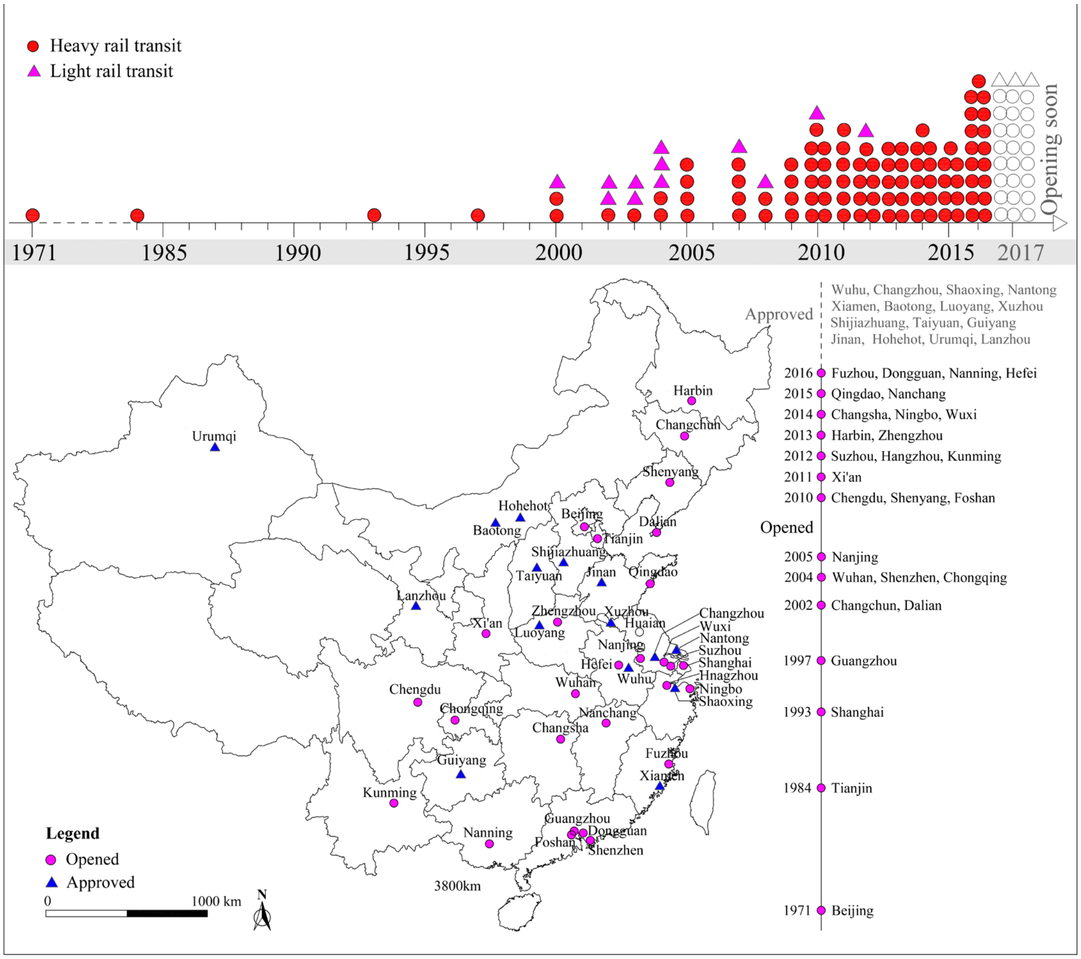

Figure 1: Development of HRT and LRT in China

3.2 Data sources

In this study the research team collected data on 109 URT projects in 28 Chinese cities. As a nationwide study, the data were collected through various methods, including surveys, interviews, online documents and web-data. The most significant challenge came from obtaining data on daily ridership and capital costs. Daily weekday ridership data were primarily collected from online documents and official websites of the 28 cities' URT agencies (e.g., Beijing Subway, 2017; Guangzhou Metro, 2017; Shanghai Metro, 2017). The capital cost figures were primarily collected from the National Development and Reform Commission of China (NDRCC, 2017) through which URT construction and investments were officially approved. Meanwhile, interviews with local URT agencies and other supplemental investigation were conducted if the ridership and capital cost data on some URT projects could not be obtained from the above-mentioned sources. Data on the independent variables were obtained directly from the local URT agencies or calculated indirectly by the functions defined in the next section of this study.

The 109 URT lines, including 97 HRT lines and 12 LRT lines, attracted daily weekday ridership of about 54.6 million in 2016. The total 2016-adjusted capital costs for these projects were about 256 billion USD (Table 1). The average cost per line of the 97 HRT lines were about 2.3 times higher than the 12 LRT lines. The average daily ridership per km of the HRT lines was 15,900, which was about 1.5 times the rate of LRT lines. In 2016, Shanghai operated the longest HRT network in China and Guangzhou operated the most effective HRT network proofed by its highest daily ridership per km.

Table 1: URT projects selected for analysis

City	HRT				LRT				Population (thousand)[a]
	Number of lines	Length (km)	DR per km (thousand)	CC per DR (USD)	Number of lines	Length (km)	DR per km (thousand)	CC per DR (USD)	
Shanghai	12	537.9	17.6	3161.1	2	57.5	13.8	4166.7	22685
Beijing	17	502.2	18.8	4820.2	2	69.1	9.5	7273.7	20390
Tianjin	4	113.1	7.5	8326.6	1	52.7	2.1	25095.2	11260
Guangzhou	7	256.4	38.8	1924.1	1	3.9	17.5	222.8	18760
Dalian	2	43.7	6.2	11412.1	1	63.5	3.4	18676.4	4300
Wuhan	4	144.8	17.3	5721.3	1	34.6	14.7	2353.7	7620
Chongqing	2	98.4	12.7	5736.7	2	96.5	13.9	6942.4	7440
Nanjing	7	258.1	10.2	6332.9					6380
Shenyang	2	55.2	14.7	4754.5					6200
Suzhou	2	63.2	12.2	6164.4					5380
Qingdao	1	25.2	5.6	17098.9					5970
Changsha	2	50.1	16.4	4923.1					3775
Shenzhen	8	282.8	17.1	4662					12240
Chengdu	4	108.6	20.3	4225.3					10680
Xi'an	3	91.4	21.9	4152.1					6150
Hangzhou	3	80.3	13.7	5764					7605
Kunming	2	42.3	7.6	11142.2					3730
Harbin	2	23.1	6.5	16496.8					4915
Zhengzhou	3	95.4	6.5	11385.3					5755
Ningbo	2	74.7	4.1	12825.3					3895
Wuxi	2	55.4	9.6	10704.3					3670
Foshan	1	32.2	6.9	10985.1					7250
Nanchang	1	28.8	14.6	6838.5					2790
Fuzhou	1	24.9	3.9	26254.3					4070
Dongguan	1	37.8	3.2	21898.3					8260
Nanning	1	32.1	12.5	7287.2					2690
Hefei	1	24.6	9.4	10429.7					3730
Changchun					2	50.7	4.1	3752.3	3435

Abbreviations: DR, daily ridership; CC, capital costs.

[a] Data source: Demographia (2016).

4 Research approach

In this section, we define the dependent variable and independent variables examined in this study. The analytical methods used to capture the factors' impacts on URT cost-effectiveness are also introduced.

4.1 Dependent variable

The dependent variables evaluated in this study include daily weekday ridership, capital costs, and capital costs per daily weekday ridership of each URT line. These variables reflect the passenger attraction, the total investment prior to operation, and the cost-effectiveness and performance of URT.

4.2 Independent variables

As many determinants affect URT ridership and capital costs, it is difficult that all the determinants could be examined in a single paper. In this study, we focus on factors measuring land-use density, project design, system service, and multimodal transit integration, which are introduced as follows.

4.2.1 Land-use density

Two variables, weighted population and job densities, reflecting land-use densities are examined in this study. For most Chinese cities, population and job densities generally decrease as the distance to the city center increases. Thus, two indicators are defined to account for the variances:

$$W\_population_{ij} = \frac{POP_i}{\frac{\sum_{s=1}^{n} d_{js}}{n_j}} \tag{1}$$

$$W\_job_{ij} = \frac{JOB_i}{\frac{\sum_{s=1}^{n} d_{js}}{n_j}} \tag{2}$$

where $W\_population_{ij}$ and W_job_{ij} are the weighted population and job densities of rail transit line j in city i, respectively; POP_i and JOB_i are the total population (ten thousand) and job (ten thousand) of city i, respectively; d_{js} is the distance of station s of line j to the city center (km); and n_j is the total number of stations of line j.

4.2.2 Project design

The project design variables reflect the design features of URT projects. Four variables are included and examined, including the full length of the line, the number of above-ground stations, the number of transfer stations, and the average station distance to the city center. The first three variables were directly obtained from the websites of URT agencies and the average stations' distance to the city center is calculated as:

$$Distance_{ij} = \frac{\sum_{s=1}^{n} d_{js}}{n_j} \tag{3}$$

where $Distance_{ij}$ is the average stations' distance of line j in city i to the city center of city i, d_{js} is the distance of station s of line j to the city center (km), and n_j is the total number of stations of line j.

4.2.3 System service

Train frequency and other variables reflecting system service have been examined as important factors in affecting URT cost-effectiveness (e.g., McCollum & Pratt, 2004; Taylor et al., 2009). In this study, four variables are examined, including 1) months since the project operated, 2) peak headways on weekdays, 3) ticket price for the full line, and 4) daily operation time.

4.2.4 Multimodal transit integration

One variable reflecting multimodal transit integration, daily bus ridership of a city, is examined in this study. Many travelers transfer between bus and URT. For instance, in Shanghai 33% of URT passengers transfer from bus (Eastday, 2011). Thus, the number of bus passengers is expected to have a positive influence on URT ridership. Due to data limitation, we could not examine other variables reflecting multimodal transport integration such as car-URT and bicycle-URT in affecting URT ridership. (For more detailed studies, see, Ji et al., 2017; Kuby et al., 2004; Sohn & Shim, 2010; Zhao et al., 2014; Zhao & Li, 2017; etc.)

In addition, HRT and LRT vary considerably in investments and ridership performance. Thus, a dummy variable of LRT indicating a URT line is LRT (=1) or not (=0) is included to account for the variances. Table 2 summarizes the descriptive statistics of the dependent and independent variables.

Table 2: Descriptive statistics of the variables

Variable	**Symbol**	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
Dependent variables					
Daily ridership (thousand)	*DR*	5	2078	501.2	434.5
Capital costs (2016 million USD)	*CC*	286.7	7089	2349.3	1065.5
Capital costs per daily ridership (2016 USD)	*CCDR*	711.0	173235.3	10685.9	19334.0
Independent variables					
Weighted population	*W_population*	20	651.2	126.5	90.1
Weighted job	*W_job*	3.7	258.0	38.6	33.7
Line length (km)	*Length*	3.9	82.4	33.1	13.5
No. of above-ground stations	*Ab_station*	0	35	4.9	7.1
No. of transfer stations	*Transfer*	0	28	4.3	4.3
Average stations' distance to the city center (km)	*Distance*	3.0	43.9	13.7	8.1
Months since operated	*Months*	1	37	6.6	6.1
Weekday peak headways (second)	*Headway*	90	1200	297.3	153.6
Ticket price for full length (CNY)	*Price*	2	25	6.3	2.5
Daily operation time (minutes)	*Time*	800	1095	986.7	56.0
Daily bus ridership (million)	*Bus*	1.2	11.1	5.4	3.2
Light rail transit or not	*LRT*	0	1	0.1	0.3

4.3 Analytical methods

In this study, the analytical methods include comparative analysis and regression analysis. The comparative analysis provides an overall view on the URT systems in China and simply compares the performance between HRT and LRT. Multiple linear regression (MLR) analysis is used to examine the impact of a single independent variable on the dependent variable by controlling for the influence of other independent variables, which is widely adopted and easily understood. The basic MLR is developed as:

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \beta_l LRT \qquad (4)$$

where Y denotes the dependent variable of daily weekday ridership, or capital costs, or capital costs per daily weekday ridership; X_i are the independent variables reflecting land-use density, project design, system service, and multimodal transit integration; LRT denotes the dummy variable of LRT or not. β_0, β_i, and β_l are the parameters to be estimated. For ridership and cost-effectiveness estimation, all the independent variables listed in Table 2 are included. The independent variables reflecting system service are not included into capital cost estimation, since factors such as ticket price and daily operation time are determined after operation and are generally not related to the investments on URT projects before operation.

5 Findings

5.1 Comparative analysis

Figures 2a-2d compare the cost-effectiveness performance between the 97 HRT lines and 12 LRT lines, presented by daily ridership, daily ridership per km, capital costs per km, and capital costs per daily ridership, respectively. The averagely daily ridership, daily ridership per km, capital costs per km, and capital costs per daily ridership for the 97 HRT lines are 520,200, 15,900, \$80.9 million, and \$11,000, respectively. These indicators of HRT are compared to LRT indicators of 349,000, 10,000, \$35.4 million, and \$6,500 of the 12 LRT lines. Unexpectedly, the averagely capital costs per daily ridership of HRT are 1.7 times the LRT's. This result gives an impression that LRT lines tend to be more cost-effective than HRT lines on average. The reasons for this result will be discussed in detail later.

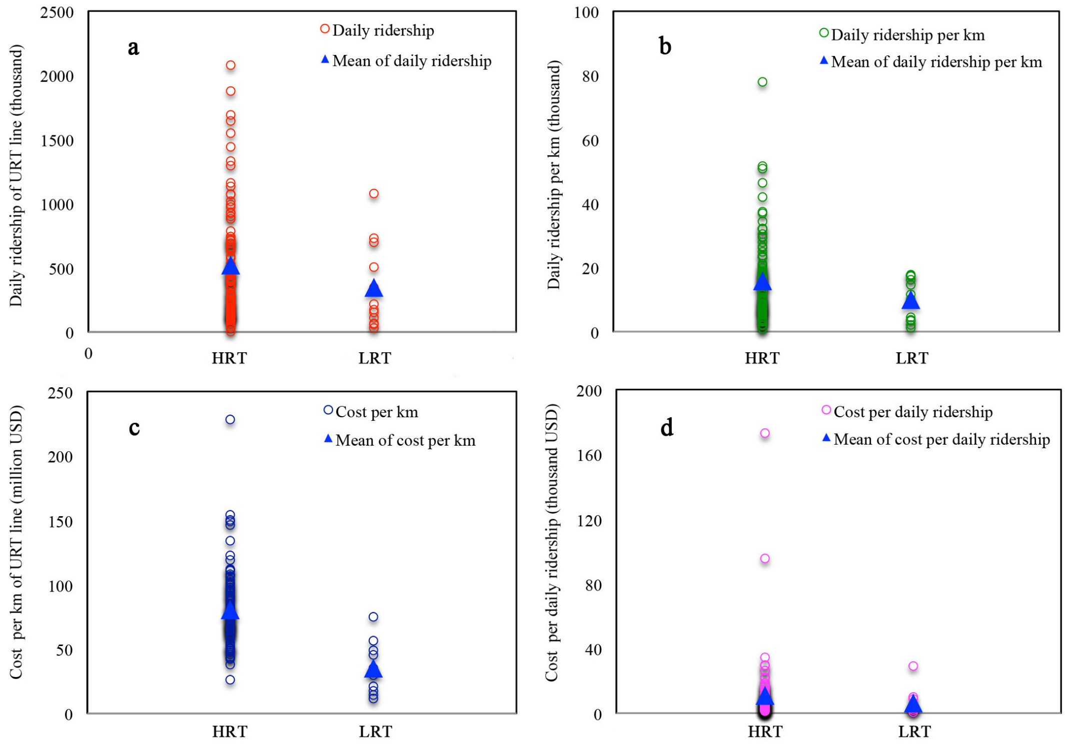

Figure 2: Comparison of the cost-effectiveness between HRT and LRT projects in China

Figures 3a-3d show the average distance between two adjacent stations, the percentage of the length of above-ground line in the full length, the ticket price per km, and the average stations' distance to the city center, respectively. The average distance between two adjacent stations for the 97 HRT lines with 2,153 stations is 1.62 km, with a minimum distance of 0.95 km and a maximum of 5.11 km. These figures can be compared to LRT line averages of 2.33 km between stations, with a minimum distance of 0.49 km and a maximum distance 9.37 km. On average, only 17.9% of the HRT lines are above-ground, compared to 83.1% of the LRT lines. In China, some LRT lines or part of them are constructed underground, such as the whole Guangzhou APM line, which is built underground, and three stations of Chongqing LRT Line 2 that were built underground. The mean ticket price per km for the 97 URT lines is 0.203 CNY (1 CNY was worth about 0.146 USD in 2018), which is lower than the 0.253 CNY of LRT. One reason is that the ticket price per km of the Beijing Airport Line and Guangzhou APM Line is 0.890 CNY and 0.508 CNY, respectively, which is higher than that of HRT lines. As hypothesized, the average station distance to the city center for the 97 HRT lines' is 13.32 km, which is about 20% closer than the 16.35 km average distance for LRT lines.

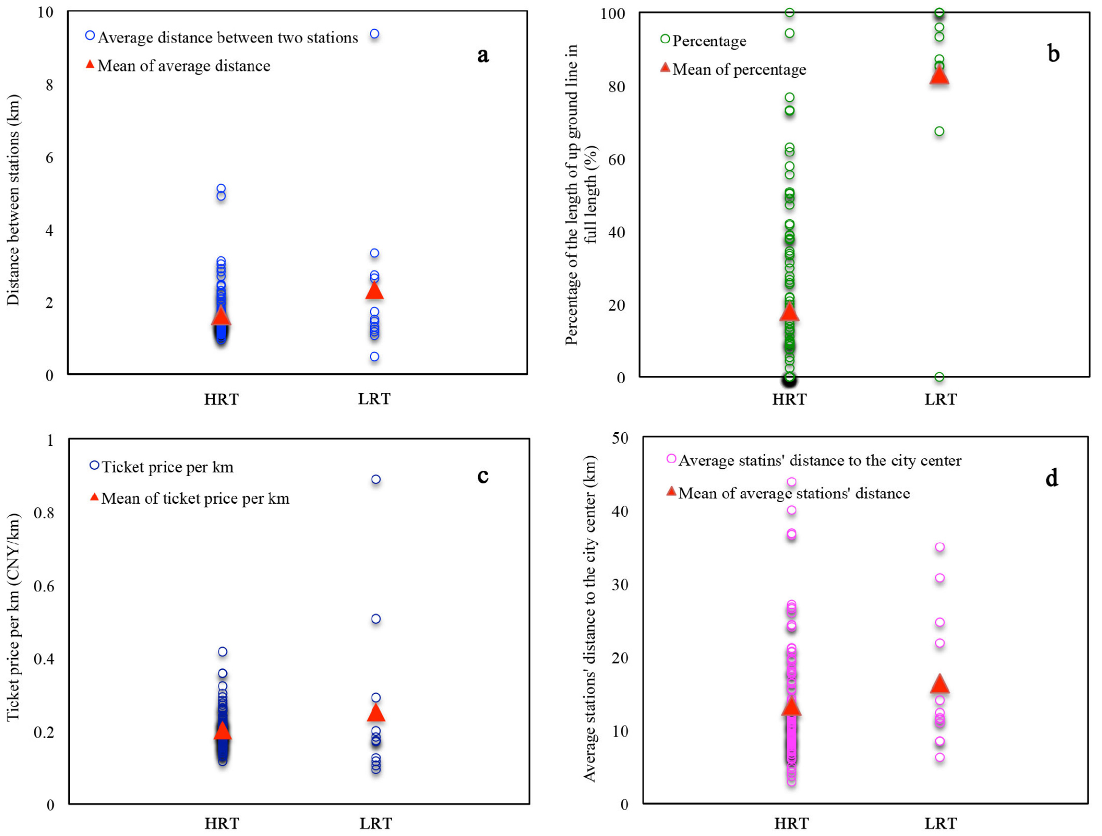

Figure 3: System features of the URT projects in China

5.2 Regression results for daily ridership

Two MLR models were constructed to examine the impacts of independent variables on daily ridership (DR). The two models are differentiated by including the number of above-ground stations in DR Model 2 and omitted in DR Model 1. The justification for omitting the stations in Model 2 is that LRT stations are generally constructed above ground. Thus, the explanatory power of the dummy variable of LRT may be diluted by including the number of above-ground stations in the model.

Table 3 summarizes the regression results. Based on goodness-of-fit, we can see that both of the models are statistically valid (p<0.001). While R2 increases by including the number of above-ground stations, the t-statistic for the dummy variable of LRT decreases from -3.92 to -1.93, and the independent variable of Ab_station is not statistically significant (p=0.206) in explaining DR. Thus, DR Model 1 is used to explain the impacts of influencing factors on DR.

Table 3: Estimation for daily ridership

DR Model 1	***B***	***t***	***p***	**DR Model 2**	***B***	***t***	***p***
(Constant)	323.55	0.50	0.619	(Constant)	359.67	0.56	0.580
W_Population	0.61**	2.34	0.022	*W_Population*	0.62**	2.37	0.020
W_Job	2.74*	1.80	0.075	*W_Job*	2.77*	1.81	0.073
Length	12.48***	4.62	0.000	*Length*	13.62***	4.80	0.000
Ab_station	/	/	/	*Ab_station*	-7.31	-1.27	0.206
Transfer	17.82**	2.24	0.027	*Transfer*	18.60**	2.34	0.021
Distance	-2.23***	-4.46	0.000	*Distance*	-1.90***	-4.10	0.000
Month	3.03***	5.62	0.000	*Month*	3.46***	5.78	0.000
Headway	-0.60***	-2.86	0.005	*Headway*	-0.60***	-2.88	0.005
Price	-14.52	-1.22	0.227	*Price*	-8.70	-0.68	0.497
Time	0.15	0.23	0.821	*Time*	0.18	0.28	0.781
Bus	28.81**	2.37	0.020	*Bus*	26.80**	2.19	0.031
LRT	-138.97***	-3.92	0.000	*LRT*	-130.16*	-1.93	0.057
Model statistics					*Model statistics*		
R^2	0.712				R^2	0.717	
Adjusted R^2	0.679				Adjusted R^2	0.681	
p	0.000				*p*	0.000	

DR: daily ridership.

"/": indicates this independent variable is not included into estimation.

*: p<0.1

**: p<0.05

***: p<0.01

The regression results indicate that both weighted population and job have significant, positive impacts on daily ridership, a finding consistent with previous studies (e.g., Kuby et al., 2004; Sohn & Shim, 2010). The estimated elasticity for line length is 12.5, indicating each additional km of URT line generates about 12,500 daily weekday ridership, controlling for other independent variables. The estimated parameter for the number of transfer stations indicates that daily URT ridership increases by about 17,800 with each additional transfer station. However, daily ridership decreases significantly with the average stations' distance from the city center and the estimated elasticity indicates for each additional km of the average stations' distance to city center, the daily URT ridership drops by about 2,200.

Daily ridership increases as time goes on. For each additional month since operation, daily ridership increases by about 3,030. This result reflects the potential of URT in attracting passengers from other travel modes. Train headway is significantly and negatively associated with daily ridership at the line level, a finding consistent with previous studies (Taylor et al., 2009; Guerra & Cervero, 2011). The estimation result indicates that for each additional second of peak headways, daily ridership at the line level decreases by about 600.

One of the interesting findings observed is the significant and positive relationship between URT ridership and bus ridership. For each additional million bus passengers, the daily URT ridership tends to increase by 28,800. Due to quite a lot of passengers transfer between bus and URT (Eastday, 2011), this result is reasonable. In addition, station-level studies also find a positive relationship between bus and URT (Kuby et al., 2004; Sohn & Shim, 2010). These findings highlight the importance of multimodal transit integration. The coefficient for the dummy variable indicating a URT line is LRT or not is estimated with a negative parameter of -139 thousand, a finding consistent with the comparative analysis in this study.

5.3 Regression results for capital costs

The capital costs (CC) models mainly examine the influence of land-use and project design related factors on URT construction investments. Similarly, the two models are differentiated by including the number of above-ground stations in CC Model 2 and omitted in CC Model 1. It is worthwhile to note that both the independent variables of Ab_station and LRT are significant in explaining capital costs, and the goodness-of-fit is improved by including both of them. Thus, CC Model 2 is adopted and explained as follows.

Table 4: Regression results for capital costs

CC Model 1	***B***	***T***	***p***	**CC Model 2**	***B***	***t***	***p***
(Constant)	1619.71***	5.06	0.000	(Constant)	1431.57***	4.64	0.000
W_Population	6.28**	2.07	0.041	*W_Population*	5.16**	2.02	0.046
W_Job	13.87*	1.72	0.088	*W_Job*	10.72*	1.75	0.086
Length	36.64***	5.22	0.000	*Length*	42.78***	6.21	0.000
Ab_station	/	/	/	*Ab_station*	-56.49***	-3.49	0.001
Transfer	21.96	0.90	0.371	*Transfer*	21.60	0.93	0.354
Distance	-20.86	-1.56	0.121	*Distance*	-13.95	-1.09	0.280
Month	21.11	1.30	0.196	*Month*	30.52*	1.95	0.054
LRT	-1579.90***	-6.02	0.000	*LRT*	-765.50**	-2.24	0.027
Model statistics					*Model statistics*		
R^2	0.466				R^2	0.524	
Adjusted R^2	0.429				*Adjusted* R^2	0.486	
p	0.000				*p*	0.000	

CC: capital cost (million USD).

"/": indicating this independent variable was not included into model estimation.

*: $p<0.1$

**: $p<0.05$

***: $p<0.01$

The regression results indicate that high land-use densities are significantly associated with high capital costs. The estimated coefficients of weighted population and weighted job are 5.16 and 10.72, respectively. Each additional km in urban rail length is correlated with an additional $42.78 million in capital costs. Both the number of above-ground stations and the dummy variable of LRT are negatively associated with the capital costs, which are estimated with coefficients of -56.49 and -765.50, respectively. By excluding the variable of the number of above-ground stations, the estimated coefficient of the dummy variable of LRT decreases significantly from -765.50 to -1579.90. These results indicate that the construction of above-ground stations could reduce the capital costs of URT, even if it is a LRT.

5.4 Regression results for capital costs per daily ridership

Table 5 summarizes the regression results for capital costs per daily ridership (CCDR). The two models are statistically valid (p<0.001) and explain a moderate variation in CCDR (0.55<R2<0.56). The most important findings come from the negative and significant coefficients of weighted population and job densities. The results indicate that higher land-use densities are associated with better cost-effective performance of URT projects, in spite of more capital costs, which is consistent with Guerra and Cervero (2011).

Table 5: Regression results for capital cost per daily ridership

CCDR Model 1	B	t	p	CCDR Model 2	B	t	p
(Constant)	92034.78**	2.27	0.025	(Constant)	92757.57**	2.28	0.025
W_Population	-150.22**	-2.12	0.037	*W_Population*	-150.50**	-2.11	0.037
W_Job	-341.26*	-1.80	0.074	*W_Job*	-341.77*	-1.80	0.075
Length	-447.76**	-2.45	0.016	*Length*	-421.72**	-2.16	0.033
Ab_station	/	/	/	*Ab_station*	-165.60	-0.40	0.694
Transfer	383.80	0.67	0.506	*Transfer*	401.22	0.69	0.490
Distance	934.25***	2.84	0.006	*Distance*	963.89***	2.84	0.005
Month	-642.14*	-1.74	0.085	*Month*	-609.32	-1.60	0.112
Headway	7.02**	2.178	0.031		7.14**	2.517	0.013
Price	588.69	0.69	0.492	*Price*	456.44	0.50	0.621
Time	-87.09**	-2.05	0.043	*Time*	-87.76**	-2.05	0.043
Bus	88.78	0.10	0.920	*Bus*	43.13	0.05	0.962
LRT	-5181.41**	-2.23	0.028	*LRT*	-4762.24	-1.99	0.048
Model statistics					*Model statistics*		
R^2	0.553				R^2	0.559	
Adjusted R^2	0.487				Adjusted R^2	0.490	
p	0.000				*p*	0.000	

"/": indicating this independent variable was not included into model estimation.

*: $p<0.1$

**: $p<0.05$

***: $p<0.01$

The dummy variable of LRT is estimated with a significantly negative coefficient, indicating LRT tends to be more cost-effective than HRT on average. This might be explained by the following explanations: First, URT ridership generally increases as time goes on. Most of China's LRT projects were put into operation before the year of 2010, whilst many HRT projects were constructed after 2010. The newly constructed HRT projects tend to attract fewer passengers than the old LRT lines. Second, although LRT may generate more noises to the residents along the lines than HRT, some, if not all, LRT lines indeed perform better than HRT in attracting passengers. For instance, with the length of only 3.9 km, the daily ridership of Guangzhou APM Line was about 70,000 in 2016, which was more cost-effective than many HRT lines. In addition, LRT Lines 2 and 3 in Chongqing also cost less but performed better than many HRT projects. While the time may offset the bad cost-effective performance of some HRT projects in China, multimodal URT systems should be developed evenly in the future rather than focusing on the development of HRT in the past decade.

6 Discussion and conclusions

Faced with the challenges caused by the rapid urbanization and motorization in China, there has been a focus on transit-oriented development across Chinese cities in recent years. In terms of transit development and promotion, cost-effectiveness is not only an important aspect to reflect the performance of URT but also a goal that is difficult to achieve. This paper introduced the development of HRT and LRT in China, and examined how URT cost-effectiveness performance varies depending on land use density, project design, system service, and multimodal transit integration. The comparative analysis on the cost-effectiveness between HRT and LRT is also a contribution of this study to the existing literature. Additionally, this study has the following implications for policy and practice concerning URT development in China.

First, it is generally cost-effective to develop URT in cities with high densities. Although investments on URT in cities with high densities are higher than with low densities, findings of this study indicate that population and job densities have significantly positive impacts on daily ridership and are negatively associated with capital costs per daily ridership. Indeed, together with the public finance budget and passenger intensity, local population is the one of the three prerequisites to the development of URT in China (The Central People's Government of China, 2018). In 2018, the local population requirements for adopting URT projects raised to 3 million and 1.5 million at the city level for HRT and LRT, respectively (The Central People's Government of China, 2018). That is, only cities with relatively high population density can get the permission from the central government to develop URT. Although the improvement in population requirement would reduce the number of cities in meeting the condition, the high requirement could potentially promote the cost-effective and benign development of URT systems in China.

Second, rather than over-focusing on the development of URT, equal attention should be paid to the effective multimodal transport integration. Bus-URT integration can paly a key role in increasing URT ridership and improving its cost-effectiveness performance. In the past decade, however, some Chinese cities intended to overemphasize the importance of URT in resolving the challenges caused by urbanization and motorization, but somehow ignored the important role of urban bus. As Figure 4 shows, the travel mode share of URT in Shanghai increased from 5% in 2006 to 16% in 2014, while the travel mode share of bus decreased from 20% to 15% during the same period (SIURCTD, 2015). Given the fact that the URT is not as flexible as bus, when the URT lines have formed the pivotal network, more efforts should be paid to multimodal transport integration rather than expanding URT network excessively.

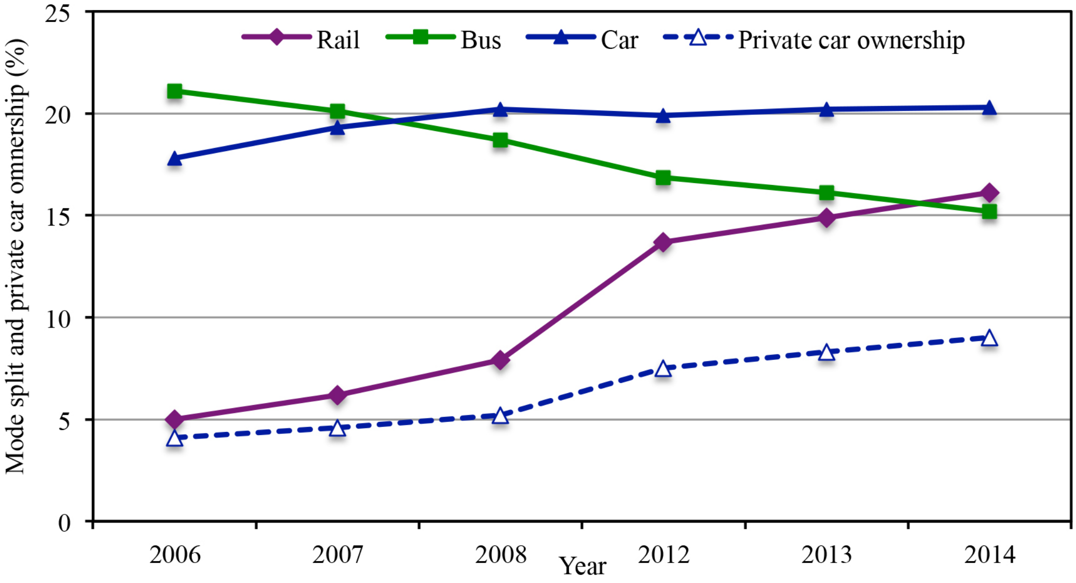

Figure 4: Travel mode share and private car ownership in Shanghai (2006-2014)
Source: SIURCTD (2015)

Third, in recent years more and more Chinese cities are keen to develop HRT and only a few LRT lines have been constructed. In contrast, LRT has gained considerable popularity in some developed countries such as the United States (Kuby et al., 2004). Findings of this study indicate that LRT in China tends to be more cost-effective than HRT on average. While this difference might be the result of the passenger's cultivation effect of LRT lines since many HRT lines just opened recently, LRT tends to be more suitable for some cities, especially the cities with complex geologic conditions such as Chongqing and Jinan. For instance, in the hilly riverside city of Chongqing, the daily ridership per km of LRT Line 2 and Line 3 were 11,600 and 16,200, respectively, which performed better than most of the HRT lines. Considering the less capital costs and good performance of LRT in passenger attraction, it is highly possible that LRT would undergo a renaissance in China in the future, as which has already occurred in some developed countries in the past decades.

Fourth, equal attention should be paid to improve the system service and operating effectiveness of URT systems. Why do obvious disparities in cost-efficiency of URT remain across different cities in China? Regardless of the land use densities and project design features, the systems' level of service tends to play an important role. Many URT projects in China are far below their designed transport capacity. The averagely hourly ridership of the 97 HRT lines was 31,700 per line (bidirectional), which was less than half of the designed transport capacity. Only 22 of the 109 examined URT lines had the weekday peak headway less than 180 seconds. However, many Chinese cities are eager to build new URT lines rather than improve the operating effectiveness of the existing lines. By effectively integrating URT with other urban travel modes and optimizing the service level of URT systems, the existing URT projects are expected attract more passengers.

To conclude, this paper has conducted a nation-wide study to evaluate the cost-effectiveness of URT projects in China. The policy implications of this study for the government, URT operators, and planners are also discussed. Besides the influence of land use density, system service and multimodal transport integration that has been examined in this study, high URT ridership level and successful URT investment undoubtedly depend on other determinants. For instance, pedestrian and cyclist friendly designs surrounding URT stations could play an important role in increasing URT ridership. Also, the value capture through URT'S surrounding land is important to compensate its investments. Many Chinese cities have a far way to go before their URT systems can develop sustainably without the huge subsidies from local governments. Successful experiences from Hong Kong, Tokyo and Singapore in practice are worth considering as well. With the rapid development of URT worldwide and especially in China, more studies on theories and practices to improve the cost-effectiveness of URT systems are expected.

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