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The impact of urban rail transit on commercial property value: New evidence from Wuhan, China

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ABSTRACT

The interaction between rail transit and the urban property market is a vital foundation for planning transit-based policy such as Value Capture and Transit Oriented Development (TOD). Yet only few studies have reported the impact of transit access on commercial property value. This paper presents empirical evidence from Wuhan, China, to enrich the knowledge in the subject area. Spatial autoregressive models were employed to estimate the commercial value capture, based on 676 observations along Wuhan's metro rail line through the main business districts. Value appreciation was discovered within the 400 m radius of road network distance from Metro stations. The transit access premiums present as two tiers: 16.7% for the 0–100 m core area and approximately 8.0% within the 100–400 m radius. The result demonstrates the potential benefit of adopting value capture and optimising TOD planning to support sustainable urban rail transit investment. Amid rapid urbanisation in China, the evidence reported here could help better inform cities, across the developing world and beyond, of the benefits of adopting rail transit-based policy.

1. Introduction

TOD planning policy and Value Capture mechanisms have been recognised as effective methods to promote the sustainability of urban rail transit around the world (Batt, 2001; Cervero and Murakami, 2009; Jillella et al., 2015; Zhao and Larson, 2011). Research on the relationship between transit investment and the urban property market is the vital foundation for transit-based policy and TOD planning. Significant literature has been published related to this field: Debrezion et al. (2007), Wardrip (2011) and Mohammad et al. (2013) reviewed nearly 200 publications in the topical area. Recent studies include Hewitt and Hewitt (2012) on Ottawa; Pan (2012) on Houston; Kim and Lahr (2014) on New Jersey; Hurst and West (2014) on Minneapolis; Dziauddin et al. (2014) on Kuala Lumpur; Macfarlane et al. (2015) on Atlanta; and Sun et al. (2015) on Beijing. Most of those studies focus on residential property, but only a few pay attention to commercial property: Cervero (2004), Kim and Zhang (2005), Pacheco-Raguz (2010), Ko and Cao (2013), Nelson et al. (2015), Mohammad et al. (2017) –though with almost no focus on developing countries. Commercial function is an essential element in the rail transit station area, so studying the association between transit and commercial property would benefit TOD policy development. In this paper, this gap is addressed with a case study from Wuhan, China.

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Over the last decade, urban rail transit system development has been booming in urban China. Wuhan offers a case, typical of Chinese cities, that invests heavily in an urban rail transit system and enables the investigation of the effect of transit access on commercial property. The local government considers rail transit not only as an antidote to resolve traffic congestion and environmental pollution from cars, but also a stimulant to promote urban development and regeneration. With three rail transit lines in operation by 2014, an additional 14 lines are planned to extend the urban rail net work over the next fifteen years. Meanwhile, Wuhan is reported as one of the most prosperous commercial real estate markets in China (Sina, 2015). However, a mountain of debt, from monies borrowed for infrastructure investment, is now threatening the economic sustainability of the city (Barboza, 2011). Poor management and organisation of the transport system and land use will potentially reduce the benefit of rail transit investment (WLSP, 2015). Studying the impact of Wuhan's urban rail transit development on land value will support the local government's ambitious plan to realise their rail transit metropolis.

This paper reports on Wuhan's past and current experience on the association between rail transit and commercial property. The empirical documentation can inform policy decision making on TOD planning, for cities around the world. This paper first reviews recent literature related to this field, including studies from Chinese cities (Section 2). The spatial hedonic price models (Section 3.1) and data sources (Section 3.2) for our study are then introduced, before presenting the positive rail access effect detected in Wuhan and its combined policies (Section 4).

2. Literature review

In the international context, a very limited number of studies refer to the value appreciation in commercial property accruing from transit proximity. Reported research is as follows: Weinstein and Clower (1999) found that community retail properties in the DART corridor (Dallas and Denver) experienced a value jump of 29% compared to other areas of Dallas Texas. In a case study of Santa Clara County, California, Cervero and Duncan (2002) found substantial capitalisation benefits for Light Rail Transit (LRT) and commuter rail, of 23% and 120%, respectively. Using hedonic pricing models, Cervero (2004) discovered both positive and negative influence on commercial property, for different rail lines in San Diego, California. Kim and Zhang (2005) reported a positive impact of transit access on commercial land in Seoul, South Korea, but the premiums differed between locations. Pacheco-Raguz (2010) reported that the amount of commercial land use increased but the land value increased slightly near to Line#1 of the Metro system in Milan, Italy. Ko and Cao (2013) found that the Hiawatha light rail system in Minneapolis, Minnesota promoted a commercial property price increase of $24.6 per square foot, with the positive effect extended to an area of approximately 0.9 miles. Nelson et al. (2015) reported that, in both Dallas, Texas and Denver, Colorado, half of the positive effect of LRT access on commercial property dissipates at 0.06 miles, and three-quarters at 0.10 miles. In a recent study on Dubai, commercial property was reported to gain almost 40% in value within a 1000-m radius from a metro station (Mohammad et al., 2017). The studies mentioned mainly demonstrated cases from car-oriented cities in developed countries and findings vary from case to case.

Following the adoption of urban rail transit in many Chinese cities, a number of studies emerged, many of which focused on the impact on residential property. The most studied city is Beijing and some empirical data were observed from its LRT lines (Wang et al., 2004) and its Mass Rapid Transit (MRT) lines (Gu and Guo, 2008; Zhang and Wang, 2013; Zheng and Kahn, 2008). A recent study by Zhang et al. (2014) compared the variation in the effect from MRT, LRT and Bus Rapid Transit (BRT) lines in Beijing, and found the MRT to have both a wider impact zone and a higher premium than LRT and BRT. Other empirical evidence is also well documented from other Chinese cities, including Shanghai (Pan and Zhang, 2008; Pan et al., 2014); Guangzhou (Salon et al., 2014; Tian, 2006); and Shenzhen (Zheng and Liu, 2005). However, to the best of our knowledge, there is no literature estimating the rail transit impact on commercial property in Chinese cities, in either international or Chinese publications. As more and more urban rail transit systems are constructed and developed, and the commercial real estate market continues to boom in Chinese cities (Miner, 2015), additional empirical analysis is vital in supporting policy decision making. This study attempts to address this gap.

3. Method and data

3.1. Method

3.1.1. Multiple linear regression (MLR)

Hedonic price modeling (HPM) could explain the market value of a heterogeneous product by estimating the implicit price of the product's attributes. The HPM technique has been widely used to derive public infrastructure impacts on property prices, from other factors (Cervero, 2004; Mohammad et al., 2013; Rosen, 1974). The multiple linear regression model (MLR), using an ordinary least-squares estimator to represent the average marginal effect of the explanatory variables on dependent variables, is the initial and conventional HPM. The MLR models may take a linear form, log-log form or a semi-log form; theory does not prescribe one specific form over the other. Choosing which modeling form depends on the sample characteristics and the evaluation of model performance. In our study, we chose the semi-logarithmic model, where only the dependent variable undergoes logarithmic transformation, as it presented better in statistical indicators in experiments with our data. In this model form, the effect of a one unit price change on distance to transit station is calculated in percentage terms. The base MRL model in semi-log form is shown in Eq. (1):

$$\ln p_i = \alpha_0 + \sum_{k=1}^{m} \alpha_k \chi_{ki} + \beta d_i + \varepsilon_i \tag{1}$$

where:

p_i: the price of the ith commercial property unit, yuan/m^2.
χ_{ki}: the kth attribute of the ith property unit.
d_i: the distance to the nearest metro station in metres (m).
ε_i: the random error term.
α_0, α_k, β: the coefficients to be estimated.

3.1.2. Spatial economic models

The MLR has several technical problems, which were summarised as the problem of non-random variables, the problem of choosing the functional form, and the problem of spatial autocorrelation in spatial data (Armstrong and Rodríguez, 2006; Diao, 2014). As location information is an essential attribute of property observations, the problem of spatial dependence and heterogeneity may lead to inefficient or even biased estimation of parameters (Anselin, 1988). One such instance is that the price of a commercial property unit is influenced by the other units, due to their spatial proximity. Researchers recommended using spatial economics models to evaluate the transit access impacts on property value (Ibeas et al., 2012; Macfarlane et al., 2015). To test and handle possible spatial autocorrelation, we applied spatial autoregressive models (SAR) and spatial autoregressive model in the Error term models (SEM). The SAR model incorporates a spatial autoregressive structure into a MRL model. The SEM model incorporates the error term to estimate spatial dependence in the disturbance process. The SAR and SEM are shown in Eqs. (2) and (3).

$$\ln p_i = \alpha_0 + \rho W \lg p_i + \sum_{k=1}^{m} \alpha_k \chi_{ki} + \beta d_i + \varepsilon_i \tag{2}$$

$$\begin{aligned} \ln p_i &= \alpha_0 + \sum_{k=1}^{m} \alpha_k \chi_{ki} + \beta d_i + \varepsilon_i \\ \varepsilon_i &= \lambda W \varepsilon_i + \mu \end{aligned} \tag{3}$$

where:

ρ, λ: the spatial autoregressive coefficient of errors.
W: the spatial weight matrix.
p_i, χ_{ki}, d_i, ε_i, α_0, α_k, β: the same parameters as in Eq. (1).

In the SAR and SEM models, the W spatial weight matrix is a central part. It represents the interaction between spatial observations which could influence the significance of test procedures (Pasquale et al., 2015). LeSage and Pace (2009)summarised several ways to create a spatial weight matrix, such the contiguity, the fixed number of neighbours and the distance threshold. Considering the spatial distribution of commercial property samples, we introduced the threshold distance method to define the W matrix during spatial dependence analysis.

3.1.3. Model selection

The MLR, SAR and SEM models have their advantages and a mis-specified model would lead to biased estimates of model coefficients and the insignificance of coefficients (Lesage and Fischer, 2008; Macfarlane et al., 2015). In this study, we used Moran's I, Lagrange Multiplier Test (LM), and the Robust Lagrange Multiplier Test (RLM), to detect whether the specification errors are caused by the dependent variables, or by the error term (LM-error) in the MLR model, so that we could choose the spatial model for the transit access effect analysis. The use of LM and RLM tests is a classical method framework, developed by Anselin (1988).

3.2. The Wuhan case

Wuhan, located at the intersection of the Beijing-Guangzhou railway and the Yangtze River, is known for being the transportation hub of China. The municipality has a total area of about 8500 km^2 and a total population of over 10 million (2014 estimate). Two rivers, the Yangtze River and the Han River, divide the urban core into three sub-areas, or "towns": Hankou, Wuchang, and Hanyang. Each "town" has multiple sub-districts. The organisation of traffic crossing the Yangtze River has become a vital problem for the city, although six bridges and a tunnel have been built. It is hoped that rail transit will help reduce traffic flow on bridges, especially in the city's core area.

In 2015, Wuhan was operating three urban rail transit lines, as can be seen in Fig. 1: light rail transit (LRT) #1, Metro rail transit (MRT) #2 and MRT#4. Wuhan began its first rail transit (LRT#1) services in 2004. MRT#2 opened to the public

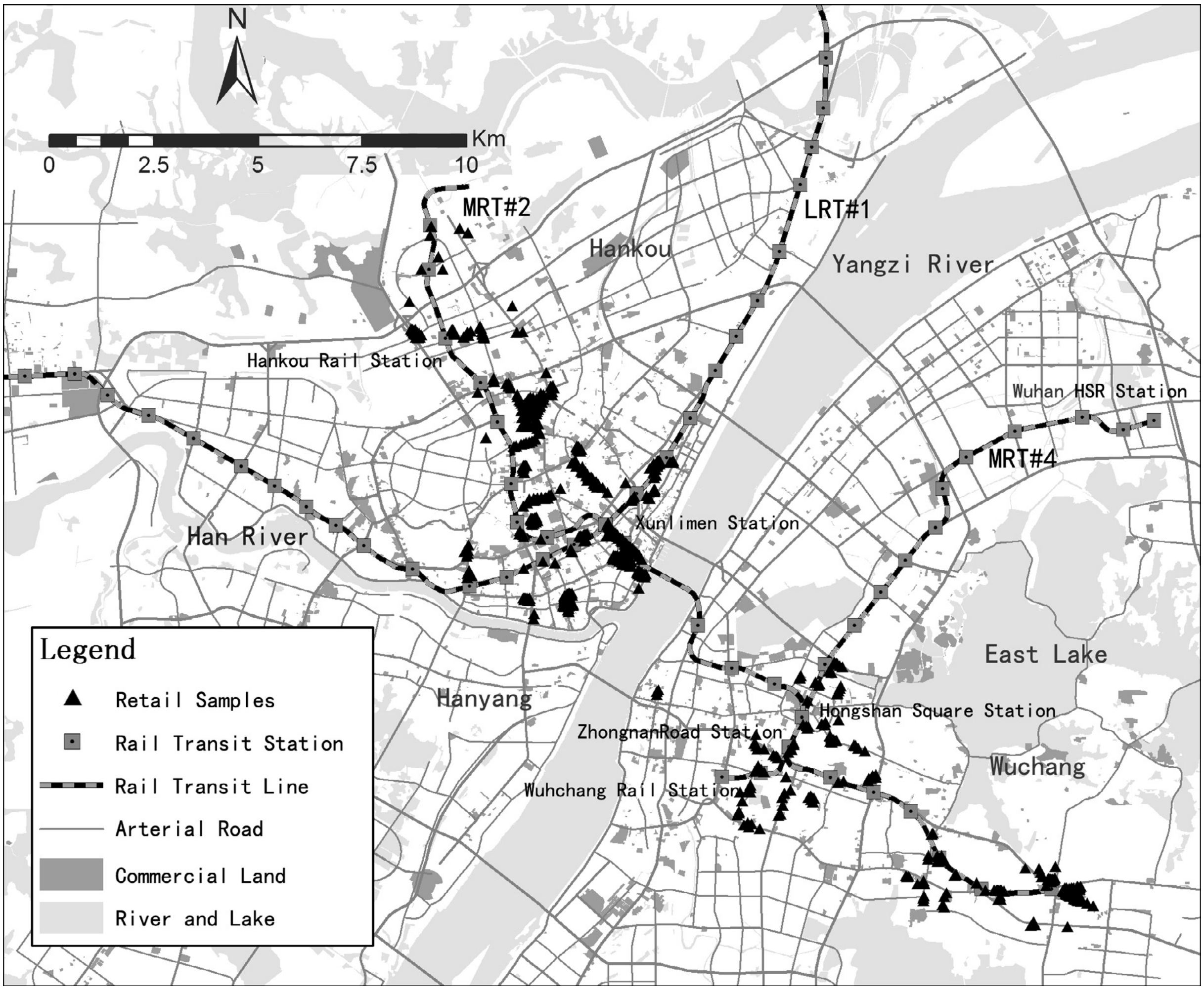

Fig. 1. Rail transit lines in Wuhan by 2014 and samples. Source: Author's work.

in 2012, and MRT#4 opened by the end of 2013. These three rail transit lines connect three national railway stations in Wuhan. The average passenger volume reached nearly 1.3 million per day in May 2015. The city government has launched a planning initiative to establish Wuhan as a Metro Metropolis. It is planned to construct a further 5 MRT lines in the next 5 years, and an additional 9 rail transit extension lines by 2030. The government also aimed at integrating regional spatial development within the framework of a rail-based transit network, supporting TOD strategic transport planning policy.

In this paper, we have selected MRT#2 for case study. MRT#2 has a total length of 28 km and 21 stations. The line, intersecting with LRT#1 at Xunlimen Station and intersecting with MRT#4 at Hongshan Square station and Zhongnan Road station, forms the spine of the three rail transit lines. In 2013, the average ridership for MRT#2 reached 650,000 per day. In operation for nearly 4 years, MRT#2 has already stimulated the real estate sub-market on the corridor. Meanwhile, MRT#2, crossing the Yangtze River, connects the two urban centres, several urban sub-centres, Hankou national Railway station and several large residential blocks. Almost all of the important commercial districts, and several district commercial centres in the city, are located on the corridor of MRT#2. The commercial property market along MRT#2, which is really active, supplied a sufficient sample for this study. However, LRT#1, which was built on the old commuter rail, crosses the old town in Hankou and connects a number of industrial districts and residential neighbourhoods. Along the MRT#4 corridor, there are many revitalised neighbourhoods and few newly-built commercial centres. Generally, along LRT#1 and MRT#4, the commercial property market was not very active and the property sale samples were insufficient for the HP model. Therefore, considering the location and commercial property market of MRT#2, and the availability of samples, this study focused only on MRT#2. We then took the further step of proposing planning improvement and policy implications.

3.3. Data source

In China's urban planning codes and standards, urban land use is classified into eight categories. The subcategory of commercial use covers land which could be developed for retail, market, restaurant and hotel use (MOHURD, 2011), and this study conforms to this definition. Properties which are used as offices or public facilities are therefore excluded from this study, as these functions fall into a different land use subcategory.

In this study, 676 samples were introduced to the HP model. For each observation, four sets of explanatory variables are considered. The first set includes the structural characteristics of the observations: number of floors, the function(s) of the building, type of commercial property, decorative condition, and whether it is new or second-hand.

The second set of variables includes time indicators. The indicator variables account for the effects of macro factors, such as inflation, economic cycles and housing reform policies, which may affect sale price. This study contains only the samples sold in 2014 and 2015, as the metro access effect presents as stable after operation.

The third set of variables describes the location characteristics of the real estate in Wuhan. The distance to the station, which is the analysis goal of this study, fits into this set of variables. As the accessibility features of the built environment is suggested as a vital element for public transport use (Aditjandra et al., 2016; Debrezion et al., 2007), this crucial parameter is measured based on the road network, in order to exactly present the accessibility from observations to a metro station. The distance from observations to the city centre, sub centre and transport hub, are measured by Euclidean distances. The business district indicators capture possible business location preference, in Wuhan.

The final set of variables characterizes the local access to public facilities and amenities, such as green space, water space (wetlands), bus routes, shopping centres, educational institutions (schools and universities), and hospitals. Binary variables were created to indicate the accessibility to these facilities. A distance of 800 m on the road network was taken as the cut-off value. Under China's planning codes, the service coverage area for many facilities-such as schools, community hospitals, and urban parks-is usually defined as the area reachable on foot within 10 min (approximately 800 m); the average spacing of urban arterials is 800 m.

The data for this study come from three major sources. The majority of samples were collected from the internet (www.soufang.com), which provided real-time, detailed transaction information for individual commercial properties, including price, physical characteristics and address. The internet data contains the asking or listed price, not the transaction price. The price information might not truly reflect the commercial property market responses to transit services. Furthermore, there were some station areas with only a small number of observations from the internet source; we therefore carried out an on-site survey for the purpose of gathering additional observations and as a validity check. The survey yielded additional data, by using a questionnaire designed to ask questions about property addresses, sale prices and structural features. The survey teams, consisting of 2–3 graduate students, visited property owners in the MRT#2 station areas, to complete the survey forms; they were able to capture previously missing or undisclosed information, such as properties sold before 2015. Both these data collection tasks were conducted in the first half of 2015. From the two first types of data source, commercial property price, the detailed address, the sale time and the variables of structural characteristics of the observations were obtained.

A further data source was the urban Geographical Information System (GIS) database, provided by the Urban and Rural Planning Bureau of Wuhan. The GIS database includes the land use, road network and buildings information, on the rail transit corridor. Based on the address information, all collected observations were added into the GIS database. Then, the two set of variables – including location characteristics and distance to local facilities – were calculated via ArcGIS 10.0. After deleting all invalid or incomplete records, the final data set contains a total of 676 samples. Table 1 presents descriptive statistics of the samples.

4. Analysis results

The analysis consists of two parts. In the first part, we built the MLR model and revised the possible multicollinearity among the variables. Then, spatial dependence was estimated, based on different spatial weight matrices, and consequently the applicable spatial economic model was chosen. In the second step, the spatial regression model was used to estimate the transit access premium on commercial property, after defining the influence area.

4.1. MLR estimates and spatial autocorrelation analysis

The study firstly built the MLR model, which introduced all 33 initial variables presumed to be implicit elements of commercial property value. Then, nearly half of the variables were progressively excluded (see Appendix A), because of the statistical insignificance at the 10% level. Meanwhile, based on the Variance Inflation Factor (VIF), the variances 'Distance to Main Centre' and 'Distance to Sub Centre' were merged into one variable: 'Distance to City Centre'. In this way we arrived at the succinct MLR, with 16 variables, and the possible multicollinearity was adjusted (shown in Table 2).

Before processing the spatial dependence test, W spatial weight matrices were created by two methods: Queen-based contiguity and threshold distance. For Queen-based contiguity, order adjacency W matrices were created, to test spatial dependence. For the threshold distance method, we proposed distance = 730 m, 900 m, 1000 m, 1200 m, 1500 m and

Table 1
Commercial property samples descriptive statistics.

	Variables	N	Min.	Max.	Mean.	St. Dev.
	Price (RMB Yuan per m^2)	676	8000	214,286	37155.64	22564.17
Structure	Floor	676	1	5	1.50	.94
	Duplex (0,1)	676	0	1	.07	.26
	Mixed with Residential (0,1)	676	0	1	.43	.49
	Mixed with Office (0,1)	676	0	1	.04	.19
	Shopping Mall (0,1)	676	0	1	.13	.34
	Commercial Street (0,1)	676	0	1	.29	.46
	Roadside Retail (0,1)	676	0	1	.20	.40
	Simple Decoration (0,1)	676	0	1	.49	.50
	Refined Decoration (0,1)	676	0	1	.32	.47
	Second hand (0,1)	676	0	1	.30	.46
Time	Sale Time (Year)	676	2014	2015	2014.90	.30
Location	Distance to Main Centre (100 m)	676	0	167	38.45	40.59
	Distance to Sub Centre (100 m)	676	0	83	23.66	14.13
	Distance to Transport Hub (100 m)	676		134	35.16	29.87
	Distance to Metro station (m)	676	10	2000	883.10	585.18
	Distance to Main Road (m)	676	10	1000	323.66	280.51
	Distance to Branch Road (m)	676	5	1000	262.55	280.23
	Xibeihu Business District (0,1)	676	0	1	.14	.35
	Zhongshan Business District (0,1)	676	0	1	.03	.16
	Hanzheng Street Business District (0,1)	676	0	1	.08	.27
	Jianghan Road Business District (0,1)	676	0	1	.25	.43
	Hongshan Square Business District (0,1)	676	0	1	.03	.17
	Zhongnan Road Business District (0,1)	676	0	1	.07	.25
	Guanggu Business District (0,1)	676	0	1	.15	.35
Local context	Bus Routesin 800-m (routes)	676	1	70	25.50	14.75
	With Plaza in 800-m (0,1)	676	0	1	.75	.44
	With Office in 800-m (0,1)	676	0	1	.91	.29
	With University in 800-m (0,1)	676	0	1	.48	.50
	With Middle School in 800-m (0,1)	676	0	1	.80	.40
	With Primary School in 800-m (0,1)	676	0	1	.84	.37
	With Stadium in 800-m (0,1)	676	0	1	.42	.49
	With Hospital in 800-m (0,1)	676	0	1	.63	.48
	With Green Space in 800-m (0,1)	676	0	1	.33	.47
	With Water Space in 800-m (0,1)	676	0	1	.33	.47
	N	676				

2000 m (730 m is the minimum radius in which all observations had at least one neighbourhood). In total, 7 matrices were constructed for the spatial dependence test.

Moran's I, LM and RLM were estimated, for the 7 matrices (Table 3). The test showed that the 'threshold Dis1000m' matrix contributes the most striking index value among the 7. Next, LM and RLM test results were compared. The LM-lag and LM-error indices are significant and similar, while the RLM-lag value (18.284) is much higher than the RLM-error value (0.349). The results recommended SAR rather than SEM. Consequently, the MLR was transformed into the SAR and SEM model, with the estimated results shown in Table 2. The indices R^2 (0.370) and AIC (−381.068) of the SAR model are both better than the MLR (0.365, −365.429) and the SEM (0.368, −367.511) model. The coefficients for the 16 remaining statistically significant variables changed as the spatial autocorrelation was corrected. Those tests recommend the SAR model, based on the 'threshold Distance 1000m' matrix, as the suitable spatial regression model. These tests demonstrated that Spatial Autocorrelation truly contributes to commercial property value and adopting spatial economic model will help improve the confidence of the modeling results.

Predicating classical urban economic theory, the SAR model demonstrates that location plays an important role for commercial land use. The increasing distances to a metro station are reducing the value of commercial property in the main business districts (Zhongsan, Hangzheng and Jianghan). Conversely, a unit increase in proximity to a metro station significantly increases a commercial property's value, although the premium is only small because the influence area is not controlled. The next section discusses this issue in further detail.

4.2. Rail transit access premium estimates

In the second part of our analysis, we first examined the spatial extent to which transit lines may have an influence on commercial property value. This was done by drawing 100 m wide concentric rings around transit stations and creating binary variables indicating the location of properties in different rings. The binary variables were introduced into the SAR model. Beyond a distance of 400 m, transit effects are rather mixed and insignificant, as demonstrated in Table 4. Therefore, the

Table 2
Comparison of the MLR, SAR, SEM models.

		MLR		SAR	SEM
		Coef.	VIF	Coef.	Coef.
	CONSTANT	4.559**	–	2.760**	4.559**
	W_LgP			0.397**	
	Lamda				0.372**
Structure	Floor	−.058**	1.205	−056**	−005**
	Mixed with Office	−.067*	1.096	−.057	−.021
	Commercial Street	.072**	1.204	.052**	.058**
	Second hand	−.076**	1.325	−.057**	−.052**
Time	Salein 2015	.071**	1.146	.072**	.054**
	Dis. To Urban Centre	−.001**	1.400	−.0001*	−.0002**
	Dis. To Transport Hub	.001**	1.245	1.2E−04**	1.7E−04**
	Dis. To Metro station	−6.381E−05**	1.592	−5.57E−05**	−6.35E−05**
	Dis. To Main Road	−9.099E−05**	1.376	−0.0001**	−7.160E−05**
	Dis. To Branch Road	−.000**	1.727	−.0001**	−.000**
	Zhongshan Business District	.161**	1.145	.174**	.154**
	Hanzheng Street Business District	.249**	2.102	.275**	.203**
	Jianghan Road Business District	.044**	1.601	.071**	.026**
Local context	With Primary School in 800-m	.050**	1.175	.055**	.025**
	With Hospital in 800-m	−.084**	1.560	−.088**	−.075**
	With Open Space in 800-m	−.044**	1.249	−.033**	−.035**
N		676		676	676
R^2		0.365		0.370	0.368
Akaike Info Criterion (AIC)		−367.511		−381.068	−378.071

Spatial weight matrix: threshold distance 1000.
** Sig < 0.05.
* Sig < 0.1.

Table 3
Spatial dependence tests based on spatial weight matrices.

	Queen contiguity	Threshold distance					
		Dis730m	Dis900m	Dis1000m	Dis1200m	Dis1500m	Dis2000m
Moran's I	−1.000	4.108**	5.585**	6.263**	5.373**	4.589**	4.256**
LM Lag	0.501	30.549**	38.223**	38.662**	26.189**	18.147**	10.426**
Robust LM Lag	−0.000	25.078**	21.502**	18.284**	12.956**	9.913**	4.674**
LM Error	0.501	8.752**	16.799**	20.727**	13.633**	8.530**	6.905**
Robust LM Error	−0.000	3.281*	0.079	0.349	0.400	0.296	1.152
LM SARMA	0.501	38.830**	38.302**	39.011**	26.589**	18.443**	11.578**
N = 676							

** Sig < 0.05.
* Sig < 0.10.

influence area on commercial property for MRT#2 could be drawn as a 400 m radius, measured in road network distance from stations.

Specifically, for price modeling we used the samples falling within 400 m of MRT#2 stations. Table 5 illustrates the modeling outputs. On the whole, commercial property prices gain an average of 9.02% (3351.44 yuan) for being in the impact zone of MRT#2 stations. The inner circle 0–100 m enjoys the highest premium, reaching 16.76% (6193.85 yuan). From 100 m to 400 m, the premium fluctuates around 8% (7.81%, 8.52%, and 7.29%). For other circles, the premiums appear in two tiers, with the turning point at a distance of 100 m by road network.

Meanwhile, other factors present an effect on commercial property value, on the transit corridor. Among the structural features, 'Commercial Street' is reported to have a positive impact (5.2%), representing the investment preference for commercial property in Wuhan. 'Number of floors' and 'Second hand' has, as expected, a negative effect. The coefficient of 'sold in 2015' is positive and significant at the 0.5% level. This means that commercial property prices increased by 7.1% from 2014.

For location features, positive coefficients are obtained for the business districts of Zhongshan, Hanzheng Street, and Jianghan Road. All three of these business districts are in Hankou town–the traditional commercial town of Wuhan. Classical urban economic theories suggest that properties closer to the city centre enjoy higher value. The coefficient of −0.0011 for 'Distance to City Centre' demonstrates this theoretical prediction as, for every 100 m closer to the activity centre, commercial property prices increase by 0.1%. 'Proximity to transport hub' and 'Main road' also presents a positive effect. Notwithstanding

Table 4
Influence area on commercial property for MRT#2 (with SAR model).

	Variables	Coef.	Std. Error	t	Sig.
	CONSTANT	2.638 **	0.366	7.196	0.000
	W_LgP	0.410 **	0.084	4.904	0.000
Structure	Floor	−0.006 **	0.001	−4.210	0.000
	Mixed with Office (0,1)	−0.028	0.038	−0.735	0.462
	Commercial Street (0,1)	0.052 **	0.017	3.036	0.002
	Secondhand (0,1)	−0.063 **	0.017	−3.640	0.000
Time	Sale in 2015	0.046 *	0.025	1.836	0.066
Location	Dis. To Urban Centre (100 m)	−0.001	0.000	−1.510	0.131
	Dis. To Transport Hub (100 m)	0.0001 **	0.000	3.035	0.002
	Dis. To Main Road (m)	−0.0001 *	0.000	−1.950	0.051
	Dis. To Branch Road (m)	−0.0001 **	0.000	2.994	0.003
	Zhongshan Business District (0,1)	0.139 **	0.048	2.928	0.003
	Hanzheng Street Business District (0,1)	0.125 **	0.038	3.231	0.001
	Jianghan Road Business District (0,1)	0.024	0.023	1.079	0.281
Local context	With Primary School in 800-m (0,1)	0.021	0.021	0.976	0.329
	With Hospital in 800-m (0,1)	−0.071 **	0.019	−3.773	0.000
	With Openspace in 800-m (0,1)	−0.036 **	0.016	−2.194	0.028
Circles	Ring 0–100 m	0.171 **	0.048	3.591	0.000
	Ring 100–200 m	0.082 **	0.028	2.946	0.003
	Ring 200–300 m	0.091 **	0.029	3.139	0.002
	Ring 300–400 m	0.078 **	0.038	2.034	0.042
	Ring 400–500 m	−0.017	0.029	−0.592	0.554
	Ring 500–600 m	0.015	0.028	0.560	0.576
	Ring 600–700 m	0.069	0.049	1.410	0.159
	Ring 700–800 m	0.009	0.029	0.305	0.760
N = 676					
R^2 = 0.371					
Akaike Info Criterion = −383.165					

Spatial weight matrix: threshold distance 1000 m.
** Sig < 0.05.
* Sig < 0.1.

this oddity, it is important to note that 'Distance to branch road' significantly increases property value, suggesting that perhaps the sample of benefitting commercial properties was well scattered across wider urban transit catchment boundaries.

For local context, being close to a hospital negatively influences commercial property price, due to pollution and cultural factors. Fengshui is widely adopted in Chinese culture; it teaches that a hospital – associated with death and disease – produces negative energy that may impact the health or business performance of people in the nearby area. The negative impact of hospital proximity was also detected for residential property in Wuhan (Xu and Zhang, 2016). Meanwhile, nearby open space reduces value, suggesting that Wuhan commercial property owners value the agglomeration effect. It is noteworthy that the mixed land use/space variable, whether in the horizontal or the vertical, does not present a significant effect on commercial property value, despite this factor being well documented as an important element in TOD planning. These discoveries should help improve urban planning along rail transit lines in Wuhan.

5. Discussion

5.1. Value capture potential

Transit-based value capture is recommended as an efficient and equitable revenue source for transit investment and operation (Ingram and Hong, 2012). Many regions and cities have adopted mechanisms to capture property value increments created by transit accessibility, such as betterment tax, accessibility increment contribution, and joint development (Medda, 2012). In China, municipal governments are introducing value capture policy to diversify financial channels for rail transit investment, including public land leases and joint development (Li et al., 2013; Salon and Shewmake, 2011; Zheng et al., 2014). The estimation of value capture potentials would provide useful experiences for cities planning to expand their rail network – especially in China.

With the empirical study findings and the GIS database, we may illustrate transit value capture under different policy scenarios in Wuhan. First we obtained GIS data for commercial land use and building areas and calculated the total commercial property along the MRT#2 corridor. Then, the average commercial property price and the average price premium were introduced, to calculate the value increment in Chinese yuan within the influence area of MRT#2. The results show that the commercial property value increment accruing from MRT#2 access amounts to approximately 8751 million yuan (see

Table 5
Transit access premiums associated with MRT#2 (with SAR model).

	Variables	Coef.	Std. error	t	Sig.
	CONSTANT	2.717**	0.428	6.349	0.000
	W_LgP	0.395**	0.098	4.028	0.000
Structure	Floor	−0.006**	0.001	−5.039	0.000
	Mixed with Office (0,1)	−0.023	0.044	−0.527	0.598
	Commercial Street (0,1)	0.052**	0.016	3.210	0.001
	Second hand (0,1)	−0.061**	0.015	−4.435	0.000
Time	Sale in 2015	0.048**	0.024	1.991	0.046
Location	Distance to Urban Centre (100 m)	−0.001**	0.000	−1.726	0.084
	Distance to Transport Hub (100 m)	−0.0001 **	0.000	2.461	0.014
	Distance to Main Road (m)	−0.0001 **	0.000	−2.202	0.027
	Distance to Branch Road (m)	−0.0001 **	0.000	3.506	0.001
	Zhongshan Business District (0,1)	0.154**	0.031	4.999	0.000
	Hanzheng Street Business District (0,1)	0.128 **	0.035	3.651	0.000
	Jianghan Road Business District (0,1)	0.022	0.022	0.967	0.334
Local context	With Primary School in 800 m (0,1)	0.018	0.021	0.866	0.386
	With Hospital in 800 m (0,1)	−0.073 **	0.018	−4.186	0.000
	With Open Space in 800 m (0,1)	−0.034**	0.015	−2.189	0.029
Impact zone	Ring 0–100 m	0.168**	0.039	4.307	0.000
	Ring 100–200 m	0.078 **	0.026	2.982	0.003
	Ring 200–300 m	0.085 **	0.033	2.587	0.010
	Ring 300–400 m	0.073**	0.033	2.182	0.029
N = 676					
R^2 = 0.368					
Akaike Info Criterion = −388.315					

Spatial weight matrix: threshold distance 1000 m.
** Sig < 0.05.
* Sig < 0.1.

Table 6
Estimation of value increments from transit access.

Distance ring	Commercial building (sq. m)	Price premium	Value increment (million yuan)
Ring 0–100 m	142928.133	0.168	892.178
Ring 100–200 m	583603.173	0.078	1691.364
Ring 200–300 m	1204937.319	0.085	3805.468
Ring 300–400 m	870876.151	0.073	2362.131
Total			8751.142
Simulation of value capture scenarios (million yuan)			
0.5% capture rate			43.756
1.0% capture rate			87.511
5.0% capture rate			437.557

Commercial building: floor area of commercial buildings and floor area for commercial in function-mixed buildings.
Value increment: commercial building * avg. price * price premium.
Avg. price: 37155.64 yuan/sq. m.

Table 6). Next, we can simulate the captured value gains. Introducing a metro value increment fee (tax) of 1% on commercial property would produce revenue of nearly 87.51 million yuan. A tax rate of 5% on commercial property value increment would generate 437.56 million yuan of captured value. This hypothetical value capture is for the existing commercial properties stock (2014) only. Assessing transit value increment tax from residential properties and offices would also generate a potential source of significant revenue to support transit operations. Meanwhile, in the Metro Metropolis planning for Wuhan, more commercial land and higher density is assigned in the MRT#2 corridor and a sizeable land value increment could be created for rail transit accessibility, in the land market. To set this in context, the operational cost of the three rail transit lines in Wuhan (LRT#1, MRT#2 and MRT#4) was 3313 million yuan in 2013 (Li and Zhang, 2014). Such value capture revenue to offset these costs could obviously be a major financial incentive for urban rail transit operation in Wuhan.

Under the current policies in Chinese cities, transit-based value capture is mainly obtained from land development or regeneration in the station area (Chang, 2014). The value increment for rail transit accessibility is usually neglected on stock property. The examination of the potential revenue from the Wuhan case could help policy makers understand the alternative options to finance the subway system. We recommend national and local governments in China to adopt various value capture policies, such as special district taxation (Zhao and Larson, 2011) and deliberated stakeholder engagement (Jillella et al., 2015), to reduce the deficits of rail transit investment and maintenance. However, there are several policy barriers, such as the current absence of annual property taxes and the practice of auctioning swathes of land (Zheng et al., 2014). Further studies are needed on the delicate transit-based value capture framework in China.

5.2. Strategic TOD planning

The interaction between the commercial property market and urban rail transit could support Wuhan's ambitious urban planning for a Metro Metropolis.

In urban master planning, commercial land use could be laid out along the rail transit corridor. According to the city GIS database, commercial land use in 2014 accounted for 4.8% of the total urban development area in Wuhan. Within a 400 m radius of the three rail transit lines in Wuhan, the percentage is not much higher, at 6.79% for LRT#1, 11.21% for MRT#2 and 6.34% for MRT#4. Commercial land use has not been concentrated on the transit corridor in Wuhan. Promoting the agglomeration of commercial land use in the Rail transit corridor, via urban planning, would fully utilize the positive externality of rail transit investment.

In the commercial district, TOD planning could be optimised. First of all, the TOD area boundary should be carefully adjusted in the commercial district. The TOD boundary is currently a fixed 800–1000 m, in Chinese cities (MOHURD, 2015). Based on the analysis in this study, the TOD boundary should be defined based on location, with the 400 m radius distance (by road network) being practicable in the commercial district. The 100 m buffer from a Metro station would be the core area for commercial use. Accordingly, if the spatial scope of the commercial district exceeds the 400 m buffer, more rail transit stations could be added to improve rail transit accessibility. Secondly, the distance-based density bonus policy is worth adopting in TOD area zoning. For the 0–100 m circle from the Metro station, highest floor area ratio (FAR) may be applied for commercial land use. Also, the density between 200 m and 400 m to the station should be given a high FAR index, in the interest of efficient use of limited land resources.

5.3. Detailed built environment in TOD design

Classic TOD theory highlighted a number of key characteristics for successful policy adoption, such as density, mixture and land/space use (diversity), and design of the built environment-well known as 3D (Cervero and Kockelman, 1997). It is interesting to discover with our case study in Wuhan that this is not entirely true, especially regarding property value. One reason for this is perhaps cultural; the typical land use characteristics in Oriental Asia are already densely populated, densely built environments, with a high degree of mixed use land/space, with an organic design to accommodate accessibility–rendering 3D insignificant in this environment. In contrast, access to the main business district, and even branch (not main) roads, are vital to the dynamics of property value. Another cultural aspect – the proximity to a hospital – showed a negative impact on property value; this could be taken into account when developing a TOD plan, although in reality, ease of access to hospital is clearly crucial to all citizens.

To optimise TOD planning in urban rail cities, it is important to take account of accessibility at all levels, as this variable significantly increases the property value and could consequently benefit the sustainability of the urban rail system.

6. Conclusion

This paper identifies the positive effect of Wuhan MRT#2 on commercial property values, via spatial regression analysis. The influence area of urban rail transit access was defined to be within 400 m radius of road network distance from the Metro stations. The 400 m radius is much tighter than the urban rail transit impact scope (700–1000 m) in residential areas (Xu and Zhang, 2016). Our findings support Debrezion et al. (2007), who suggested that rail transit access capitalisation for commercial property concentrates in a 1/4 mile buffer from rail stations, even though Nelson et al. (2015) found in his Dallas, Texas case that the transit access effect on retail occurred only within 0.10 miles (Table 7). Furthermore, this study found that commercial properties in the inner 0–100 m circle appreciate the most (nearly 16%), while the outer three circles gain less, at circa 8%. The Wuhan MRT#2 transit access premiums present on two levels, with the 0–100 m circle being the core area. Finally, the study suggested that using value capture methodology to collect the incremental fees/taxes of land value could support sustainable urban rail transit development and benefit TOD urban planning policy.

Drawing from Table 6, it can be concluded that the main contribution of our study is the positive impact that the value capture mechanism can bring for promoting TOD planning, for a city adopting urban rail transit as its main strategic, sustainable public transport policy. This is especially the case for cities in China, where urban rail transit has been adopted as the backbone of public transport systems.

While the positive impact of value capture is transferable across different regions, the implication of TOD policy can differ from one place to another. For many Chinese cities adopting urban rail transit policy, it is important to improve accessibility to the main business district, as well as branch road access, to increase property values to the benefit of sustainable urban rail systems.

Table 7
Comparison to related studies.

	Cervero (2004)	Debrezion et al. (2007)	Nelson et al. (2015)	Mohammad et al. (2017)	This study
Case	San Diego County, USA	13 Cases (Mainly from USA)	DART in Dallas and Denver, USA	Dubai, UAE	Wuhan, China
Rail type	LRT and Commuter Rail	LRT, MRT, Commuter Rail and Heavy Rail	LRT	MRT	MRT
Method	HPM (MLR)	Meta Analysis	HPM (MLR)	Difference-in-differences Method, and HPM	HPM (SAR)
Main finding	+91.1% for being in 1/4 mile buffer from commuter rail station; +71% for 1/2 mile buffer from one LRT line; insignificant impact for other 3 LRT lines	11.2% for being in 1/4 mile buffer from rail station, negative effect as distance increase in global area	Half the retail premium dissipates at about 0.06 miles, and three-quarters of the premium dissipates at 0.10 miles	Nearly 40% for being within1500 m of an MRT station	Nearly 16% for 0–100 m circle and nearly 8% for 100–300 m by road network distance

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Appendix A. Estimated parameters of the MLR models

		MLR#1		MLR#2		MLR#3	
		Coef.	VIF	Coef.	VIF	Coef.	VIF
	CONSTANT	4.511**	–	4.539**	–	4.559**	–
	W_LgP						
	Lamda						
Structure	Floor	−0.056**	1.322	−0.056**	1.294	−0.058**	1.205
	Duplex	0.045	1.332				
	Mixed with Residential	−0.022	1.932	−0.016	1.842		
	Mixed with Office	−0.052	1.180	−0.057	1.146	−0.067*	1.096
	Shopping Mall	−0.028	1.660	−0.028	1.542		
	Commercial Street	0.048**	1.959	0.052**	1.906	0.072**	1.204
	Simple Decoration	−0.018	2.136				
	Refined Decoration	0.000	2.236				
	Second hand	−0.070**	1.513	−0.067**	1.465	−0.076**	1.325
Time	Salein 2015	0.070**	1.245	0.072**	1.181	0.071**	1.146
Location	Dis. To Main Centre	0.000	7.868				
	Dis. To Sub Centre	−8.466E−05	2.253				
	Dis. To Urban Centre			−0.001*	1.507	−0.001**	1.400
	Dis. To Transport Hub	0.001**	3.188	0.001**	2.901	0.001**	1.245
	Dis. To Metro station	−5.963E−05**	2.038	−5.946E−05**	1.887	−6.381E−05**	1.592
	Dis. To Main Road	−8.171E−05**	1.578	−8.418E−05**	1.455	−9.099E−05**	1.376
	Dis. To Branch Road	−0.000**	2.073	−0.000**	1.815	−0.000**	1.727
	Xibeihu Business District	0.044	2.285	0.039*	1.722		

(*continued on next page*)

Appendix A (*continued*)

		MLR#1		MLR#2		MLR#3	
		Coef.	VIF	Coef.	VIF	Coef.	VIF
	Zhongshan Business District	0.175**	1.235	0.174**	1.196	0.161**	1.145
	Hanzheng Street Business District	0.285**	3.032	0.275**	2.418	0.249**	2.102
	Jianghan Road Business District	0.087**	3.133	0.071**	2.361	0.044**	1.601
	Hongshan Square Business District	0.017	1.385	0.004	1.217		
	Zhongnan Road Business District	−0.009	1.805	−0.004	1.449		
	Guanggu Business District	0.065	6.932	0.056	3.296		
Local context	Bus Routes within 800 m	0.000	1.667				
	With Plaza in 800-m	0.013	1.845				
	With Office in 800-m	0.016	1.666				
	With University in 800-m	0.000	1.501				
	With Middle School in 800-m	0.002	1.369				
	With Primary School in 800-m	0.055**	1.586	0.055**	1.197	0.050**	1.175
	With Stadium in 800-m	0.010	1.780				
	With Hospital in 800-m	−0.100**	1.829	−0.088**	1.648	−0.084**	1.560
	With Green Space in 800-m	−0.009	1.653				
	With Water Space in 800-m	−0.029	1.673				
	With Open Space in 800-m			−0.033**	1.363	−0.044**	1.249
R^2		0.369		0.370		0.365	
Akaike Info Criterion (AIC)		−344.171		−365.429		−367.511	
N		676		676		676	

** Sig < 0.05.
* Sig < 0.1.

Appendix A illustrates 3 MLR models which progressively excluded outlier variables. The First hedonic model (MLR#1) introduced all 33 initial variables presumed to be implicit elements of commercial property value. Insignificant variables (at the 10% level) without similarity in other subdivisions were removed in MLR#2. For example, 'bus routes within 800m' was excluded, but 'Mixed with Residential' was retained. The variables 'green space' and 'water space' were merged into one parameter called 'open space', since the two parameters had similar function as recreation areas. According to Variance Inflation Factor (VIF), we found 'Distance to Main Centre' and 'Distance to Sub Centre' to be highly correlated and merged these into one variable: 'Distance to City Centre', which indicates the distance from a house to its nearest urban main centre, or sub centre. Model MLR#2 showed several parameters were still insignificant, despite solving the multicollinearity problem. All variables insignificant at the 10% level were excluded. In this way, we reached MLR#3 (The MLR in main body) where all the 16 variables were statistically significant at the 1% level. The SAR and SEM models were built based on MRL#3.

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