Creating sustainable urban built environments: An application of hedonic house price models in Wuhan, China

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ARTICLE

Creating sustainable urban built environments: An application of hedonic house price models in Wuhan, China

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Abstract Due to rapid urbanization, automobility, and industrialization, the increasing desire to protect environments and satisfy residents has led to an emphasis on the creation of sustainable urban environments in China. This paper is an empirical study using hedonic price models to examine a comprehensive set of environmental sustainability elements including green space, transit systems, and central business districts (CBDs) and compare their relative importance in Wuhan, China. The results show that among all housing characteristics, environmental sustainability elements had the greatest impacts on house prices. Natural water resources have the most significant positive effects on property values when they are integrated with cultural, tourism, and commercial resources to form natural recreation clusters or areas. Also, home buyers are willing to pay more for housing clusters or subdivisions with proximity to CBDs. In addition, the significant negative effects of light rail on house prices within a 1-mile radius indicate that it has not become an attractive amenity to home buyers, due to combined effects of other neighborhood amenities, little land use diversity, and the fare system. These results have implications for local and regional governments in setting priorities for sustainable development.

Keywords Built environment · Sustainable development · Light rail · Green space · Hedonic house models · GIS

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1 Introduction

Since the 1980s, a series of housing reforms have been implemented to improve housing conditions in two dimensions in China: quantity and quality of housing. Through almost three decades of efforts, housing shortage problems have basically been successfully addressed. However, problems with quality of housing, including buildings and their surrounding environments, have not been solved and have led to a failure to meet residents' needs. Especially in recent years, environmental pollution and ecological degradation due to rapid urbanization, automobility, and industrialization have worsened residential environments and have raised concerns over urban sprawl (Du et al. 2010; Zhang 2007). Between 2000 and 2005, in China, the growth rate of urban areas increased by 9 %—twice the growth rate of urban populations (PDO 2010; SSB 2009). In addition, the average number of privately owned automobiles per hundred households in China grew from 0.5 to 8.8 between 2000 and 2008 (SSB 2009). Rapid automobility and urban expansion have resulted in declining transit shares and increases in average trip lengths, which has caused serious air pollution and congestion (Zhang 2007). Also, industrialization has created problems with water conservation, ecological conservation, and environment protection in China (Du et al. 2010; Friedmann 2005). Thereby, China has set down a basic national strategy of sustainable development after decades of housing and economic reforms (Zhang and Wen 2008).

Learning how to build favorable and sustainable housing has become more important than ever before in China and has increasingly attracted attention from researchers, practitioners, and policy makers. However, little research has identified and priced sustainable elements of buildings' surroundings, the built environment that consumers favor, especially in the Chinese context (Li and Wu 2004), although a large body of studies have focused on green features in building sustainability, such as green roof technology and solar systems (Li et al. 2007; Yin 2005; Zhang et al. 2011). Developers have very limited knowledge of consumers' preferences among different sustainable elements, and how much they are willing to pay for these preferred elements, although they are aware of certain amenities and disamenities of urban landscapes (Chen and Jim 2010; Osland and Thorsen 2008). This limited knowledge often results in a failure to meet the housing needs of residents and gain comparative advantages for developers.

Green space, urban rail systems, and mixed land use in a central business district (CBD) can be important elements of built environmental sustainability in housing and urban development. These elements can be integrated into an urban built environment to control urban sprawl, build recreational opportunities of communities, and improve the quality of life for residents (CNU 2010). Green space, including open water and parks, is a significant component in health promotion (Stokols et al. 2003) and plays important roles in improving the health of cities and their residents (Hartig et al. 2003). They can also provide esthetic amenities and recreational opportunities (Jim and Chen 2007). Additionally, a continuous green infrastructure interconnected by green spaces and pathway systems can help create an urban growth boundary and prevent urban sprawl (Li et al. 2005; Schrijnen 2000). Urban rail systems, as another sustainable element of urban built environments, are pursued to control rising traffic congestion and worsening environmental conditions by reducing car use (Cervero 1998; Cervero and Murakami 2009). Moreover, they can also create sustainable finance as an urban revitalization or economic development stimulator. Finally, the mixed-use development in a CBD has also been considered as one of the sustainable forms of urban built environments (Yang 2005). Mixed land use can make neighborhoods compact and compatible with existing communities and local cultures to bring lively and sustainable urban life (CNU 2010). These elements are particularly important to large Chinese cities, which are facing challenges posed by rapid urbanization, industrialization, and automobility. Nevertheless, the economic benefits of these elements in urban sustainability have been inadequately assessed by existing studies. The lack of relevant scientific measurements has constrained their wider appreciation and application to urban planning and housing development by developers and governments. Valuing these sustainable elements could significantly contribute to understanding their important roles and determining priorities among them in urban sustainability.

This study uses hedonic housing price methods to identify and price elements of built environmental sustainability, to measure their relative importance, to discuss their application in urban built environments, and to explore strategies for creating sustainable and favorable built environment in China. This research uses Wuhan City as a study area to answer the following two research questions: What is the relative importance of three different elements of environmental sustainability, green space, transit systems, and CBDs? What are the combined effects of these three elements? Regarding these three elements, the following sub-questions can be posed: (1) Are accessibility effects of the light-rail line capitalized into the properties along the light-rail line? Does the light-rail line generate transit-oriented urban environment and transit-related benefits? (2) How do natural water resources affect local housing prices? (3) Is the CBD associated with higher housing prices?

2 Literature review

Due to the complexity of urban development, unpredictable environmental patterns, and local contexts, the research on the economic evaluation of sustainable urban built environment does not obtain generalizable results (Hess and Almeida 2007; Ryan 1999), although some studies in Western countries reveal the economic benefits of elements of environmental sustainability. Transit systems and CBDs have both positive and negative impacts on housing prices. First, most studies find positive effects of transit systems on property values from a planning and property development sense, such as improved commute times, a boom to downtown, and increased property values (Anderson 1970; Cervero and Duncan 2002; Pior and Shimizu 2001). Cervero and Murakami (2009) contend that transit systems not only provide financial and property development benefits, but also play a larger role in creating transit-oriented development (TOD), one vital form of sustainable urban development, through reducing private automobile use and encouraging transit riding. However, a few studies find negative or no significant effects from the transit system on housing prices due to noise pollution, high auto ownership in the area, or other factors (Chen et al. 1998; Nelson 1992).

Second, accessibility to a CBD has a positive influence on housing prices since the CBD has a particularly high density of job opportunities and relevant attractions, such as cultural centers and entertainment businesses (Osland and Thorsen 2008; Wong 2008). However, several studies indicate that due to suburbanization and the decline of downtown areas, proximity to a CBD can have a negative impact on housing prices (Heikkila et al. 1989; Hoch and Waddell 1993; Kain and Quigley 1970; Song and Knaap 2003). Last, proximity to green space is another critical housing characteristic influencing housing prices. The value of a property falls with increased distance from water (Brown and Pollakowski 1977; Darling 1973; McLeod 1984).

Compared to Western countries, few studies have been carried out on China to examine economic impacts of these elements in housing and urban sustainable development. Moreover, the existing research focuses on the valuation of green space (Chen and Jim 2010; Jiao and Liu 2010; Jim and Chen 2006, 2007; Kong et al. 2007), paying little attention to transit systems and CBDs. Existing studies find visibility and accessibility of green space, such as urban parks, residential gardens, and water bodies, were positively valued by providing both recreational opportunities and esthetic amenity benefits in China's cities. Jim and Chen (2006, 2007) indicate that both green space view and the proximity to water bodies have notably enhanced residential housing prices in Guangzhou and Shenzhen, respectively though some discrepancies exist between the old town and the new town. View of green spaces and proximity to water bodies raised housing price by 7.1 % and 13.2 %, respectively, within four multi-storied residential precincts with similar design in Guangzhou (Jim and Chen 2006). In Shenzhen, the view of residential gardens was found to have a statistically significant positive impact on apartments, attracting a large 17.2 % premium (Chen and Jim 2010). A study conducted in Jinan considers both the distance to and the size of the nearest green space, including the scenery forest, park, or plaza, to indicate that the size–distance indices of these green spaces have statistically significant relationships with housing prices (Kong et al. 2007). Jiao and Liu (2010) build a spatial hedonic model to value the environmental amenities with regard to their specific scale of influence in Wuhan, and their study shows similar trends.

Compared to green space, few studies examine the economic impacts of transit systems on housing prices in China, and all existing studies are limited to Hong Kong, Shenzhen, Guangzhou, Beijing, and Shanghai. The success of Hong Kong's "rail + property" development program is internationally known and has attracted the attention of both academic and government fields (Cervero and Murakami 2009; So et al. 1996). Cervero and Murakami (2009) find housing price premiums in the range of 5–30 % in property projects with a transit-oriented design in Hong Kong. Chen and Jim (2010) find that the proximity to metro stations resulted in a 3.78 % premium in Shenzhen. Zheng and Kahn (2008) and Zhang and Wang (2013) have documented the capitalization effects of proximity to subway stations and bus terminals in Beijing. Pan and Zhang (2008) find the transit proximity premium of 152 Yuan per square meter for every 100 m closer to a metro station in Shanghai, while Tian (2006) finds an increase of 5,449 Yuan per housing unit for every minute reduction in walking time to metro stations in Guangzhou. On the other hand, currently in China, 20 cities have rail systems and three cities have light-rail systems. Also, 26 other cities have plans for building new rail transit systems. In addition, many Chinese cities approach the size and density thresholds justifying rail investments. Thus, opportunities for creating both sustainable finance and sustainable urban environment through bundling residential development and railway investments in large Chinese cities are largely untapped. Taking advantage of these opportunities requires an understanding of the influences of transit systems on housing prices, which has not been adequately studied in mainland Chinese cities.

The research regarding impacts of CBD on housing prices does not obtain consistent results in Chinese cities. Four studies reported that the accessibility to the CBD is positively correlated with housing price in Hong Kong, Guangzhou, Hangzhou, and Beijing (Hui et al. 2007; Jim and Chen 2006, 2007; Ling and Hui 2013; Qin and Han 2013; Wen et al. 2005). Hui et al. (2007) indicate that apartment prices would change inversely with the travel time to the CBD. Jim and Chen (2006, 2007), Qin and Han (2013), Ling and Hui (2013), and Wen et al. (2005) find similar trends in Guangzhou, Beijing, and Hangzhou, respectively. However, another three studies show that proximity to the CBD is not a significant factor in Jinan (Kong et al. 2007), Wuhan (Jiao and Liu 2010), and Shenzhen (Chen and Jim 2010).

After reviewing the literature, it can be seen that these elements play important roles in determining property prices. However, the previous studies have given limited clues as to how house prices relate to transit systems. Furthermore, no studies were carried out on the relative importance of these three types of elements. This is because these studies dealt with only one or two types of sustainable elements. The hedonic value of these sustainable elements might be affected by omitted variables. This study analyzes a more comprehensive set of elements. Therefore, this study provides opportunities to measure the relative importance of these different sustainable elements, which has not been studied before. This measurement of relative importance can provide implications for urban planners and policy makers in setting priorities for sustainable urban development.

3 Research method

3.1 Study area

Wuhan City, the capital of Hubei Province, is the largest city in Central China. Wuhan has abundant natural water resources. Water bodies account for 26.1 % of the total land area (Wuhan Almanac 2008). The Yangtze River and the Han River converge in the center of the city and divide Wuhan into three parts: Hankou, Hanyang, and Wuchang. Also, Wuhan is known as the “City of Lakes” since 166 lakes are distributed in the city. Among them, 43 lakes are located in urban areas and 123 lakes are located in suburbs. Hence, conservation of water resources is a key issue and concern (Li et al. 2010).

In the last three decades, Wuhan City has experienced rapid urbanization and great urban sprawl. It has been faced with the biggest challenge of environmental conservation since the Chinese government designated Wuhan as a significant area of Central China’s developmental strategies that resulted in an economic boom in recent years. The pollution and depletion of natural resources caused by the local population and general socioeconomic growth has been serious (Li et al. 2010). Currently, rapid urban development has encroached on much of the water bodies both qualitatively and quantitatively (Du et al. 2010). Between 1978 and 2009, the built-up areas have expanded from 197.01 to 450.77 km^2 while the population has grown from 5.48 to 8.28 million (Wu and Xie 2011; WUPB 2008). Between 1978 and 2007, the total area of lakes decreased by 530.7 km^2, a 5.7 % decline (Li 2008), especially in Hankou. Hankou has the sharpest decline of 29 % among the three parts of the city (Zeng and Lu 2008). Therefore, quantitative information in the economic benefits of water resources can provide a basis for future urban planning to prevent encroachment onto water bodies and preserve and utilize them well.

Wuchang, Hankou, and Hanyang, respectively, serve as the educational and cultural center, the commercial and financial center, and the industrial center. This study selected the Jiang’an and Jianghan districts of Hankou as the study area because three types of essential elements of built environmental sustainability, including the CBDs, light-rail line, and water bodies, are all located in this area. The study area presents many key features in the Wuhan urban built environment and housing market. Therefore, our study of this area can shed light on urban housing policies, built environmental studies and planning, and economic and social development. According to the Wuhan Statistical Yearbook 2010, the study area is 37.71 square miles. The total population is 1,149,571 including 421,514 households.

Jiangbei business district in the Jianghan district, between the Yangtze River and Jiefang Avenue, has been the main commercial center of Wuhan since its establishment in 1927. The business district had long housed businesses, embassies, and municipal government offices. And it is home to large sport and convention venues. Also, the Riverside Park and Zhongshan Park areas in the district were developed for recreation and entertainment space. In addition to Jiangbei business district, a 1.62-mile-long “Financial Street” across the Jianghan district and Jiang’an district is a financial center of the city, which includes more than 20 skyscrapers, and 200 international or national financial institutions. These districts are interspersed with business, residential, recreational, and green areas.

Wuhan’s light rail began service in July 2004. The first phase of the No.1 line follows the alignment of Jinghan Avenue, from Wuhan No. 17 Middle School in the Qiaokou district to Xunlimen Hotel in the Jianghan district, then to the Yongqing business area in the Jiang’an district (See Fig. 1). The total length is 6.59 miles, and there are 10 stations.

3.2 Data and explanatory variables

Data on housing prices and housing characteristics were obtained from the Wuhan Housing Management Bureau website (http://www.whfg.gov.cn/). To avoid potential bias due to housing market segmentation, the chosen residential projects were all commercial. Low-rent housing provided by the government as social welfare was not included in the study. Also, only housing clusters of the mass residential sector excluding uncommon single-family houses and villas situated in the Jianghan and Jiang’an districts were included in this study. Records with missing data for any of the characteristics were dropped from the analysis. This process yielded a sample of 118 housing clusters sold between 2000 and 2007 out of a total of 466 sites.

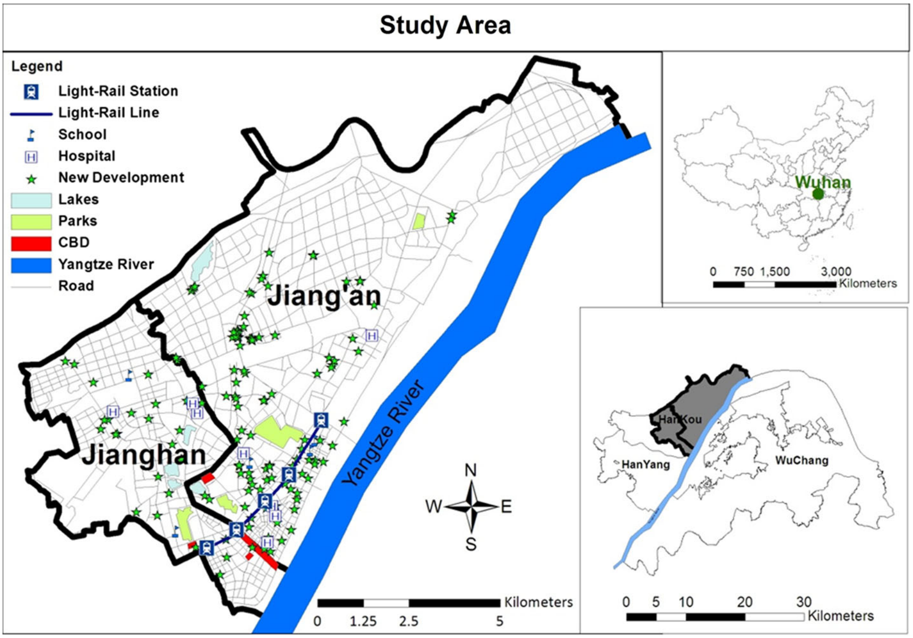

Fig. 1 Study area

The financial variables were measured in real terms using the Wuhan Real Estate Index to deflate the series. This price deflator series is published by the Wuhan Housing Management Bureau, with the base year of 2000. The housing price is inflation adjusted by the Wuhan Real Estate Index. All market prices were adjusted to March 2000. The dependent variable is the average housing price of the dwelling units or houses in a housing cluster, expressed in Yuan per square meter. Based on the literature review, local contexts, and availability of data, 16 independent variables representing structural, locational, and neighborhood attributes were chosen.

Locational variables provide measurement of travel costs from every housing cluster to different sustainable elements, including the light rail, the CBDs, the Yangtze River, the lake, and the park. The variables "LRStoB," "CBDtoB," "ParkstoB," and "LakestoB" measure the distance from every housing cluster to the nearest light-rail station, CBD, park, and lake, respectively. In addition, the variable "YJtoB" measures the distance from every housing cluster to Yanjiang Avenue. Yanjiang Avenue is a road alongside the Yangtze River. Thus, this variable can be used to approximately represent the distance to the Yangtze River. Beside this road is the core area of the Yangtze River recreation space, including many attractions, such as historical landmarks, religious activities, ecotype leisure, and more. This recreation space, built between 2001 and 2004, is a symbol of tourism and recreation in the city. This variable is expected to have a positive sign. Due to the limitation of data quality, all above distances are straight line calculated using GIS, which do not consider walk time based on road network.

Two structural variables, GFA and Stories, respectively, measure the average total floor area and the number of stories in a housing cluster. The variable "Furnished" is a dummy variable indicating whether or not developers have already furnished dwelling units before sale. Neighborhood variables Green, FAR, TFA, and NB, respectively, measure the green area ratio, the floor area ratio, the total floor area, and the number of buildings in a housing cluster or subdivision. The variable CMPM reflects the quality for community management and property maintenance level. Additionally, the variables School and Hospital measure the distance from each housing cluster to the nearest reputable school with high college enrollment rates and major hospital. Last, the variable Commercial indicates whether there exist commercial areas in a housing cluster.

3.3 Model

Based on Rosen's (1974) hedonic price model, the housing price is the sum of the implicit prices for bundles of housing characteristics (Goodman 1989; Williams 1991). In this paper, locational attributes represent and reflect the sustainable elements of urban built environments surrounding a house. The relationship between housing prices and the housing attributes was used to explore what sustainable elements most greatly influenced the housing price in Wuhan, and how much the residents were willing to pay for each element.

There is no universal guidance from current theories about the choice of functional form so far (Cropper et al. 1988). Various functional forms have been applied in empirical studies, such as linear (Hess and Almeida 2007; Kong et al. 2007), semi-log (Jim and Chen 2007), and Box–Cox form (Huh and Kwak 1997). Linear models are applied in the hedonic literature because of the ease with which the parameters can be interpreted (Hess and Almeida 2007; Kong et al. 2007). However, there is no reason to expect the functional form to be linear (Rosen 1974). Following previous studies, this paper employs linear and semi-log hedonic price functions because the distribution of data on a scattergram plot showed no parabolic or exponential curve. The linear function is expressed as the Eq. 1, and the semi-log function is expressed as the Eq. 2:

$$P = \alpha_0 + \sum \alpha_i Z_i + \varepsilon \quad (i = 1\text{–}16) \tag{1}$$

$$\ln P = \alpha_0 + \sum \alpha_i Z_i + \varepsilon \quad (i = 1\text{–}16) \tag{2}$$

where α_i represents implicit price coefficients, Z_i represents relevant housing characteristic variables, ε represents random error and α_0 is a constant. The model's regression estimation is the ordinary least squares method (OLS). The index of variance inflation factor (VIF) was used to monitor the multicollinearity between housing attributes and the consequent instability of estimates (So et al. 1996).

The hedonic price model includes one transit access variable, which is defined by the distance to the nearest light-rail station. Given the influence scale of the light-rail line, three analysis scenarios were developed for each functional form. Housing clusters within 1 mile of the light rail have significantly higher average prices compared to those beyond 1 mile (See Table 1). Therefore, the first scenario assumes that the light rail has influence on all dwelling units in the whole study area. Another two additional scenarios are used to test the difference in the effects of the light rail on housing prices within two distance ranges: The second scenario indicates the effect of the light rail within 1 mile, while the third scenario indicates the effects of the light rail beyond 1 mile. Piecewise-linear functions are used to model the effects of light-rail line within these two different distance ranges. The piecewise-linear function is expressed as the Eq. 3:

$$P = \begin{cases} \alpha_0 + \alpha_1 Z_1 + \sum \alpha_i Z_i + \varepsilon & \text{if } Z_1 \leq 1 \text{ mile } (i = 2\text{–}16) \\ \beta_0 + \beta_1 Z_1 + \sum \beta_i Z_i + \varepsilon & \text{if } Z_1 > 1 \text{ mile } (i = 2\text{–}16) \end{cases} \tag{3}$$

where α_i and β_i represent implicit price coefficients, Z_1 represents distance to the light-rail line, Z_i represents other relevant housing characteristic variables, ε represents random error and α_0 and β_0 are constants.

4 Results and discussions

Table 2 shows the obtained coefficient parameter estimations of linear regression. An adjusted R^2 of 0.606 indicates that the model explains 60.6 % of the variation in residential housing prices. The Durbin–Watson (D–W) value of 1.747, greater than 1, shows no evidence of serial correlation. The observed F-ratio of 12.239 exceeds the critical value of 1.75 for the 5 % significance level, which indicates good fitness, and the model has statistically significant predictive capability. Also, the plots of residuals versus predicted value indicate that these models are consistent with the constant error variance assumption (See Fig. 2). Among VIF values of all variables, five VIF values are greater than five, indicating potential multicollinearity. The five variables with potential multicollinearity are the distance to the light-rail station, the distance to the Yangtze River, the distance to the CBD, the distance to lakes, and the distance to schools.

Table 1 Average housing prices within different distance ranges of the light rail

Range (within mile of light rail)	<0.25	0.25–0.5	0.5–1	1–2	2–3	>3
Average price (RMB)	4,454.38	4,547.39	4,746.57	3,331.11	3,339.03	2,487.47

Table 2 Results of regression models

Variables	Scenario one			Scenario two			Scenario three		
	Unstandardized coefficients	Standardized coefficients	*T* value	Unstandardized coefficients	Standardized coefficients	*T* value	Unstandardized coefficients	Standardized coefficients	*T* value
Constant	1,828.162		3.406	1,738.320		1.113	1,795.700		3.755
LRStoB	0.238	0.542	1.885*	0.808	0.456	2.455**	−0.121	−0.284	−1.004
YJtoB	−0.192	−0.490	−1.977**	−0.636	−0.699	−1.745*	0.193	0.588	1.896
CBDtoB	−0.174	−0.492	−2.040**	0.046	0.081	0.183	0.199	0.803	1.745*
ParkstoB	−9.745E− 4	−0.002	−0.013	−0.002	−0.001	−0.006	−0.304	−0.673	−3.940***
LakestoB	−0.022	−0.039	−0.303	−0.464	−0.654	−0.006	−0.208	−0.614	−2.684***
GFA	0.388	0.060	0.850	0.734	0.063	0.282	−0.098	−0.027	−0.292
Stories	20.573	0.278	2.607***	19.984	0.259	0.921	1.122	0.017	0.140
Furnished	273.071	0.136	1.994**	363.737	0.219	1.242	167.166	0.096	1.115
Schools	−0.090	−0.198	−1.359	0.102	0.097	0.485	−0.076	−0.241	−0.741
Hospitals	−0.002	−0.003	−0.024	0.125	0.120	0.463	−0.151	−0.408	−2.357**
FAR	34.455	0.210	1.926*	44.580	0.308	1.058	30.670	0.160	1.263
CMPM	135.868	0.098	1.529	267.535	0.201	1.303	65.677	0.068	0.769
GREEN	4.371	0.058	0.722	−3.731	−0.057	−0.327	16.720	0.239	2.547**
TFA	0.001	0.074	0.873	3.892E − 4	0.029	0.112	0.001	0.084	0.757
COMM	−60.808	−0.046	−0.734	−285.037	−0.206	−1.523	67.436	0.076	0.918
NB	−1.137	−0.018	−0.218	−2.271	−0.009	−0.036	−2.165	−0.060	−0.591
Adjusted R^2	0.606			0.478			0.600		
Durbin–Watson	1.747			1.770			2.030		
F-ratio	12.239			3.520			7.739		
Sample size	118			45			73		

* Significant at the 10 % level; ** significant at the 5 % level; *** significant at the 1 % level

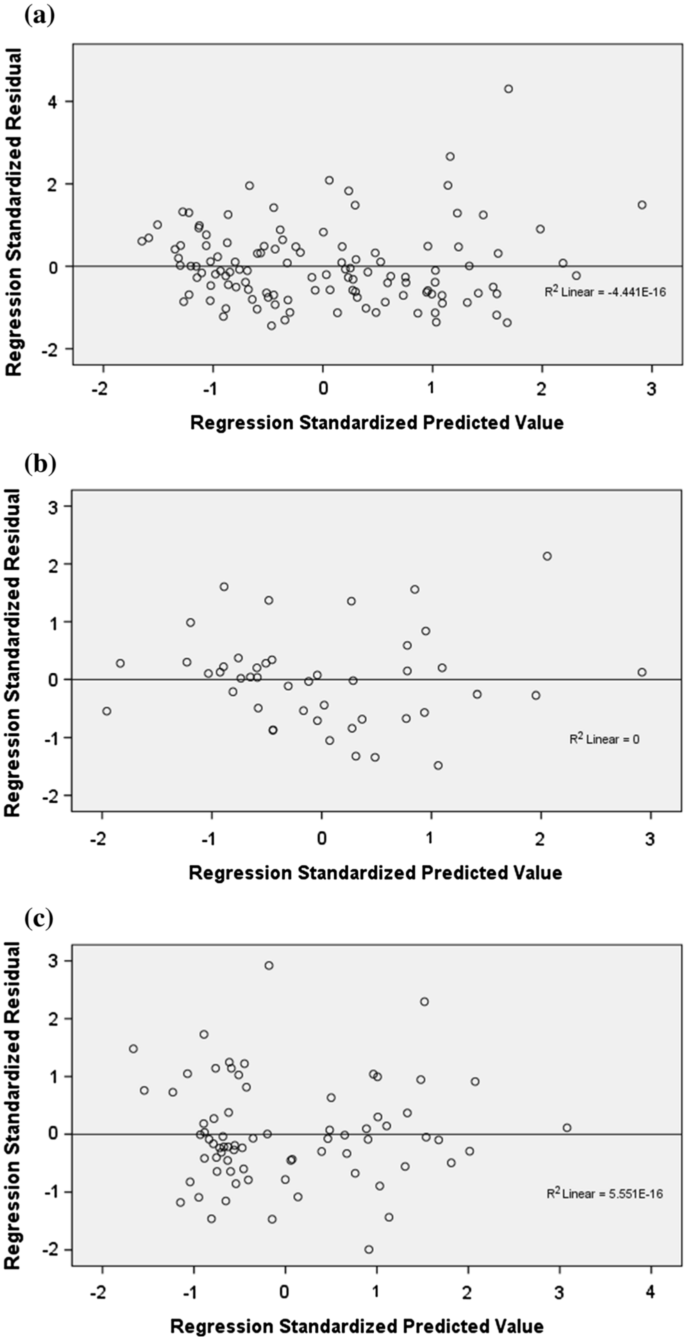

Fig. 2 Plots of residuals versus predicted value. **a** Scenario one, **b** scenario two, **c** scenario three

Table 3 Collinearity diagnostics of scenario one model

Dimension	Eigenvalue	Condition index	Variance proportions					
			Constant	LRStoB	YJtoB	CBDtoB	LakestoB	Schools
1	12.215	1.000	0.00	0.00	0.00	0.00	0.00	0.00
2	1.565	2.794	0.00	0.00	0.00	0.00	0.00	0.00
3	0.729	4.094	0.00	0.00	0.00	0.00	0.00	0.00
4	0.584	4.573	0.00	0.00	0.00	0.00	0.00	0.00
5	0.487	5.006	0.00	0.00	0.00	0.00	0.00	0.00
6	0.426	5.353	0.00	0.00	0.01	0.01	0.03	0.00
7	0.244	7.081	0.00	0.00	0.00	0.00	0.00	0.01
8	0.228	7.318	0.00	0.00	0.00	0.00	0.03	0.01
9	0.170	8.475	0.00	0.00	0.00	0.00	0.01	0.02
10	0.116	10.246	0.00	0.01	0.00	0.00	0.01	0.00
11	0.082	12.171	0.00	0.01	0.01	0.00	0.04	0.30
12	0.058	14.515	0.00	0.03	0.02	0.00	0.01	0.01
13	0.045	16.409	0.00	0.02	0.00	0.00	0.01	0.02
14	0.024	22.625	0.02	0.00	0.01	0.07	0.08	0.01
15	0.015	28.296	0.01	0.03	0.08	0.34	0.70	0.31
16	0.007	40.390	0.11	0.46	0.38	0.35	0.06	0.13
17	0.003	63.685	0.85	0.46	0.48	0.22	0.00	0.17

Collinearity diagnostics were performed to examine the correlation between these five independent variables (see Table 3). The dimension stands for a linear combination of variables. Eigenvalue stands for the variance of that combination. The condition index is a simple function of the eigenvalues. The condition index is greater than 30, indicating potential collinearity problems. Collinearity is identified by finding two or more variables with large variance proportions (0.50 or more) that correspond to large condition indices (30 or greater). However, there do not exist two or more variables whose variance proportions are greater than 50 % that correspond to condition indices greater than 30. Therefore, there is no evident multicollinearity.

The scenario one model shows that at a significance level of 10 %, six independent variables are statistically significant. They are the distance to the light-rail station, the distance to the Yangtze River, the distance to the CBD, the number of stories, the floor area ratio, and whether furnished or not. All but two variables, the distance to the light-rail station, and floor area ratio, have signs as expected. The standardized regression coefficients are used to compare the influence degree of each housing characteristic on the housing price. Among these housing characteristics, the variables representing three sustainable environmental elements had the greatest effects on the price. The greatest is the variable the distance to the light-rail station. The second is the distance to the Yangtze River, while the distance to the CBD ranks third.

4.1 Proximity to the light rail

The most significant result of the scenario one is the relationship between the housing price and the distance to the light-rail station. Proximity to the light rail has a negative effect on housing prices. Furthermore, based on the scenario two and the scenario three, there exists a positive relationship between the housing price and the distance to light-rail station within 1 mile from the light-rail line; but beyond 1 mile, there is no statistically significant relationship between them. As the distance to the light-rail station decreases by 1 km, the housing price decreases by 808 Yuan per square meter. The implicit price estimates offered by the semi-log coefficients for the scenario one assigned 7.7 % of the selling price to the distance to the light-rail line.

The result is the opposite of what was expected. This finding is different from most studies on the impact of light rail on housing prices in existing studies (Cervero and Duncan 2002; Ferguson et al. 1988; So et al. 1996). Most studies indicate that due to lower travel costs and shorter travel time, proximity to a light-rail line has a positive influence on property value (Anderson 1970; Cervero and Duncan 2002). In general, these studies are relatively context specific (Hess and Almeida 2007). The geographical context, including other amenities within the neighborhood, land use diversity, and socioeconomic status, might explain the results of this study.

First, other amenities in the area within 1 mile of the light-rail line, including recreational areas along the Yangtze River and the CBDs, may lead to a negative valuation of proximity to the light-rail line. The area within 1 mile of the light-rail line covers 19 neighborhoods, approximately 8.5 square mile of land. It houses a population of some 0.68 million people and has about 0.23 million dwelling units. These dwelling units are almost all apartment buildings. The boundaries of the area to the southeast are set by the recreational area along the Yangtze River, the Hankou area limits, and to the northwest by the Jianshe Avenue, a boulevard leading directly to one of main commercial centers, “Financial Street.” The start of the Jiangbei business district forms the southwestern boundary. The Laodong subdistrict (called “Jiedao” in Chinese), the least-dense neighborhood including a city park with the area of 0.18 square mile, and the Wuhan Tiandi District, a vibrant mixed-use development featuring restaurants, retail shops, entertainment venues, and luxury residential apartments and office space, bound the northeast side. As we mentioned in the Sects. 4.1 and 4.2, the recreational area along the Yangtze River and the CBDs has strong positive effects on housing price. Their combined positive effects are stronger than the effect of the light-rail line, which results in the decreased housing price with decreasing distance to the light-rail line.

Second, land use within this area is not diverse enough to connect the residential area with other functional areas by transit. Based on the principles of TOD, diversity means a mixture of land uses, housing types, and building styles within neighborhoods (Cervero and Kockelman 1997). A standalone transit without connecting with other mixed-use nodes will do little to prompt people to patronize public transit (Cervero and Murakami 2009). However, within the neighborhoods close to the light-rail line, the connections between the transit and land uses are weak—there is a lack of corresponding neighborhood supporting facilities, such as shopping centers, restaurants, and service outlets, especially in Jianghan district. Four-fifths of the length of the line is located in the Jianghan district. Along the segment in the Jianghan district, the majority of the land is used for residential purposes; very little land is used for open space and public lands, such as parks and governments, and almost no land is for commercial use. The lack of land use diversity may well explain its insufficient attraction to housing buyers.

Third, a light rail is a reliable, comfortable, green, high-speed public transportation, but it is expensive to build and maintain and less flexible in its operation than bus services (Loo and Li 2006). As with most transit operations, Wuhan’s current light rail is economically unsustainable and has to obtain a large amount of subsidies from the government to operate

(Li 2005). The light-rail fare is relatively high compared to the bus fare, but still does not provide enough income to cover operating costs. The relatively high light-rail fare decreases the attractiveness of the light rail as a convenient and fast transportation mode. Also, a survey in Wuhan indicates that more than 70 % of respondents' expense on public transportation is lower than 100 Yuan per month (WATPD 2006); thus, while the light rail offers higher speed and a more pleasant environment inside a train than a bus, the income level and relatively slow living pace of local residents make them unwilling to pay a light-rail fare more than twice that of the bus fare. This finding indicates the significant role of local human culture in integrating a light-rail line into a truly sustainable design. Urban design needs to be rooted in and evolve from indigenous urban culture. Moreover, the current light-rail is just the first part of the whole light-rail route, which is too short to exploit its advantage of high speed. Therefore, the appropriate urban design should be pursued to take full advantages of this vital sustainable element and permit public transit to become a viable alternative to the automobile.

4.2 A cluster of recreational activities along the Yangtze River

The second greatest effect on the Wuhan housing price indicates that the strong positive effect of proximity to the Yangtze River is capitalized into higher housing prices. The Yangtze River is integrated with special riverside landscapes, historical and religious significance, and recreation opportunities to form a cluster of activities where residents can have beautiful views, taste the nature, and experience local culture. The area along the Yangtze River is forming a recreational business center. Buyers are willing to pay an extra 192 Yuan per square meter to be 1 km closer to the Yangtze River. Proximity to the Yangtze River is important by contributing 6.0 % to the price. This finding matches the market reality that the banks of the Yangtze River are dominated by expensive residences. The finding is similar to other research results that have proximity to rivers as being a positive effect on housing prices. Urban residents enjoy living near natural water resources (Stokols et al. 2003), such as rivers, lakes, and ponds (Jim and Chen 2006; Wen et al. 2005), regarded as one of important sustainable environmental elements.

However, this study also finds that the distance to lakes has no statistically significant relationship with housing prices in Wuhan. Therefore, it is concluded that in Wuhan, water bodies alone do not have influences on housing prices. Only if these water bodies are integrated with other cultural, tourism, recreation, and economic resources to form natural recreation areas will they have a great impact on housing prices. This result confirms that, on one hand, the pollution and depletion of water bodies are reducing their attraction to housing consumers. On the other hand, the recreation cluster along the Yangtze River confirms the economic value of water bodies: Residents are willing to pay for the truly sustainable elements and designs. Thus, green space needs to be integrated with local environment shown in indigenous urban, architectural, and landscape patterns to provide esthetic amenities, cultural experiences, or recreational opportunities for urban residents.

4.3 Access to the CBDs and mixed-use development

The model result indicates that the proximity to the CBDs has a positive influence on housing prices. With every kilometer closer to the CBDs, housing prices increase at the rate of 174 Yuan per square meter. The CBDs contribute 4.9 % of the price. This finding is different from some studies in Western countries that indicated a positive relationship between housing prices and the distance to CBDs, due to the decline of surrounding environments and population losses in an area (Heikkila et al. 1989; Hoch and Waddell 1993; Kain and Quigley 1970; Song and Knaap 2003). However, in China, one sees the opposite results, in that the proximity to the CBD has positive influences on housing prices in Shanghai (Hao and Chen 2007) and Hangzhou (Wen et al. 2005). This study shows that in Wuhan, similar to other cities in China, the impact of the distance from the CBDs on housing prices reflects not only a general urban attraction effect but also the impact of mixed-use development. The CBDs in Wuhan are a "live-work-play" mixed-use development. By applying the mixed-use principle, the CBDs are creating both a lively urban life and a sustainable built environment in Wuhan.

5 Conclusion and implication

Most previous studies have confirmed the positive price effect of one set of sustainable environmental elements, green space, on residential properties. However, very few studies have analyzed a comprehensive set of sustainable environmental elements and compared the relative importance of different types of elements in China, although the important roles of light-rail lines and CBD in economic growth and urban development have been recognized in Western countries. Our study constructed hedonic price models to value urban green spaces, the light-rail line, and CBDs in Wuhan City, a densely populated city with abundant natural water resources. First, we found that among all housing characteristics, elements of environmental sustainability had the greatest impact on housing prices. Secondly, the most significant effect on property values was the light-rail line. The negative effects of proximity to the light-rail station on housing prices within a 1-mile radius indicate that the current line of the light-rail system did not benefit property value around it, due to combined effects of other neighborhood amenities, little land use diversity, and the fare system. Last, water bodies have significant positive impacts on property values when they were integrated with cultural, tourism, and commercial resources to form a natural recreation cluster or area, although they alone do not have positive effects on housing prices due to pollution and depletion of water bodies.

Our endeavor has two practical implications for government policies on creating a sustainable and favorable built environment. First, the negative effects of the light-rail stations on housing prices within a 1-mile radius indicate that, so far, the current line of the light-rail system did not generate transit-oriented urban environment and transit-related benefits. Future stages of the light-rail construction may consider integrating principles of sustainable development to construct a TOD model and joint development through land use diversity. The transit design needs to be fully integrated with land use to create a sustainable built environment. The areas surrounding the light-rail lines should have mixed urban functions, and pedestrian- and cyclist-friendly designs. In addition, effects of other neighborhood amenities on housing price indicate that the light-rail effect cannot be isolated from other amenities in the neighborhood. Thus, amenities within the light-rail service area should be carefully considered, examined, and analyzed to maximize the benefits of transit investment when the light-rail routes and stations are planned.

Second, positive effects of water bodies integrating local cultural, esthetic, and commercial resources will enable the government to create a favorable and sustainable built environment by taking full advantages of these natural resources to build recreation business districts (RBDs). These RDBs should be compatible with the existing local urban, architectural, and landscape patterns. Thus, they can help develop residential areas, promote local economic growth, provide active recreational activities, and reserve water and ecological resources. Additionally, it is implied that the open water may be linked with other urban resources to create green infrastructure systems. In order to develop these RBDs and green infrastructure systems, the government should give higher priority to the protection of these environmental resources and preservation of historic resources. The urban planning department of Wuhan City can introduce Environmental Impact Statements into the process of residential planning and policy decisions, as they have already been applied in industrial planning in order to protect natural resources and environments. Also, the government needs to initiate green infrastructure planning to help communities make better use of existing green infrastructures and determine the extent of potential growth.

6 Limitation and future works

Admittedly, these sustainable elements are the most powerful explanatory variables in this hedonic housing model. A space-contiguous study always shares the limitation of spatial autocorrelation. Neighborhood properties tend to have similar locational characteristics and share environmental elements. So, their independent contributions to housing prices are difficult to disentangle. More studies are required to examine these possible spatial autocorrelation relations. In addition, the various housing clusters or subdivisions may not be homogeneous with respect to all the structural variables, so the assumption of a single unified market may bias the results. But due to the limitation of the small sample size resulting from data aggregation at the housing cluster or subdivision level, there are not enough samples to analyze different submarkets. In the future, how to create sustainable built environments within different submarkets will be further examined when the data at the dwelling unit level is available.

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