An Integrated Model of Urban Spatial Structure: Insights from the Distribution of Floor Area Ratio in a Chinese City

Abstract

The monocentric city model has been challenged for its predictive power in urban spatial structure as multiple centers rise from the spatial expansion and functional diversification of modern cities. To overcome the deficiency of the model in explaining contemporary cities, this study takes Haikou City in China as an empirical case to develop an integrated city model that depicts the urban spatial structure by combining multiple monocentric city models, the basic unit in analyzing an urban space. The applicability of this integrated city model in Haikou is also examined in return by using the measure of floor area ratio and the method of geographical weighted regression. Results show that the traditional spatial structure of Haikou as a provincial capital where production activities are concentrated in the city center has been challenged by the emerging tourism function along the sea coast over the past decades. Compared with the long-existing monocentric “city” model around the city center that exerts a strong, asymmetrical, and unevenly distributed marginal effect on the urban space, the newly developed monocentric “city” model along the coast has a weak, one-sided, and evenly distributed marginal impact on its urban spatial structure. Therefore, the current spatial structure of Haikou City can be depicted by an integrated city model composed of two monocentric “city” models based on different “centers” with distinct urban functions. In this sense, this integrated city model developed on the monocentric city

model will be inclusive and extendable to the analysis of the dynamic spatial structure of a multi-center city.

Keywords

Urban spatial structure, polycentric city model, floor area ratio, geographical weighted regression, Chinese city

1. Introduction

Modeling urban spatial structure has received extensive and continuous research attention in the field of urban and economic geography. The classical monocentric city model, formulated by Alonso (1964) and broadened by Mills (1967; 1972) and Muth (1969), is the most influential depiction of urban space in the 20th century, in which the residential bid-rent curve is developed on the assumption that all production activities occur in the central business district (CBD).

However, this assumption has been challenged since the model was formulated. On the one hand, the ever-increasing city size induces diseconomy, raises marginal costs, and violates agglomeration economies, which lead to the initiation of production decentralization. This sprawling process has been substantially accelerated by the continuous advances in transport technologies through cutting communication costs among firms over the past decades (Anas, 1990; Louf & Barthelemy, 2013; Odland, 1978; Sultana & Weber, 2014). Against this backdrop, employment subcenters emerge with population expansion and technological advancement, as observed in many cities, such as Chicago, San Francisco, Montreal, and so on (Arribas-Bel & Sanz-Gracia, 2014;

Bender & Hwang, 1985; Cervero & Wu, 1997; Coffey & Shearmur, 2001; McDonald & Prather, 1994; McMillen & Smith, 2003). On the other hand, most cities are highly diversified in many aspects compared with their 1970s counterparts. Commodities with dissimilar techniques and requirements for land attributes (Hartwick & Hartwick, 1974), firms with multiple units and distinctive activities (Ota & Fujita, 1993), labor market with heterogeneous workers (Helsley & Strange, 1990), and households with different tastes (David & White Michelle, 1993) simultaneously emerge in one city. Their disparate location preferences give rise to multiple “centers” or nuclei in the city, thereby causing the modern metropolis to be increasingly characterized by the presence of multiple activity nodes that perform diverse economic and spatial functions (Lee, 2007). In this sense, the combination of variegated functions makes the spatial structure of contemporary cities increasingly complicated, whereas the monocentric city model gradually seems to be a “utopia” that exists only in the imagination of theorists.

Consequently, with the rise of multiple centers that stem from the spatial expansion and functional diversification of cities, an “either-or” debate on whether the monocentric city model remains effective in depicting urban spatial structure is raised. Some believe that despite the changing nature of cities and a general consensus on the existence of subcenters, the monocentric city model remains its predictive power in urban spatial structure (Baumont, Ertur, & Gallo, 2004; McMillen, 2006; Spivey, 2008). Others, on the contrary, contend that contemporary metropolitan areas bear little resemblance to the monocentric city model (Giuliano & Small, 1991). Brand-new

models — especially polycentric city models — are thus developed to better understand the spatial structure of contemporary cities (Anas, 1990; Fujita & Ogawa, 1982; Ota & Fujita, 1993). Nevertheless, monocentric and polycentric city models are not necessarily competing and incompatible with each other but can be viewed as complementing ones at different scales. An urban spatial structure shaped by multiple centers not only fits in with the polycentric city model at the city level but can also be regarded as an integration of several monocentric “city” models at local levels. In this sense, various models that are formulated to depict urban spatial structure can be synthesized into an integrated city model, in which the monocentric city model is used as the basic unit to illustrate an urban space. In this respect, the integrated city model will be inclusive and extendable in analyzing urban spatial structure under different situations — whether mono or poly centric.

Existing empirical studies on urban spatial structure have mostly been written in the context of developed countries, where the transformation of cities has occurred in the closing decades of the past century (Glaeser & Kahn, 2001; Musterd & Kloosterman, 2001). Inconsiderable knowledge exists about the urban spatial structure in developing countries, where the transformation from production city to consumption city has diversified the ways in which people live and city functions in this century. Extant studies have mainly used indirect measures — employment and population density — rather than direct measures — capital–land ratio [e.g., land value, floor area ratio (FAR)] — to build urban spatial models in fuzzy rough ways (Barr, 2012). Therefore, this study,

taking Haikou City in China as the case, FAR as the measure, and geographical weighted regression (GWR) as the method, sheds light on how the integrated city model suggested above can be developed to explain the urban spatial structure of a diversified city in developing countries. Specifically, to build an integrated city model through the case of Haikou, the following questions are stressed. Do different centers that stem from corresponding city functions produce their own monocentric “city” models? How far can these monocentric “city” models influence? Do these centers exert an evenly distributed marginal effect on an urban space within their influencing area? How the overall urban spatial structure is constructed by these monocentric “city” models? How an inclusive and extendable integrated city model can be developed using these monocentric “city” models?

The remainder of this paper is organized as follows. The subsequent section provides a critical review on the existing literature examining urban spatial structure with different models and measures. The study area, data, and methods are then elucidated. This is followed by two monocentric “city” models that are developed respectively to explore the ways in which two city “centers” with different functions and spatial attributes shape the urban space. Based on empirical findings, an integrated city model is established to explain the formation of the overall urban spatial structure and its advantages are illustrated. Finally, the integrated city model from integrating monocentric “city” models is proven to be inclusive and extendable in analyzing the spatial structure of a city that evolves gradually from monocentricity to polycentricity.

2. Literature review

2.1. Models

The monocentric city model developed by Alonso (1964), Mills (1967), and Muth (1969) has functioned as a dominant paradigm in the development of urban economic theory and been the subject of repeated empirical testing in the latter half of the 20th century (Fales & Moses, 1972; Macauley, 1985; McDonald & Bowman, 1979; McDonald, 1989; Thurston & Yezer, 1991). Based on neo-classical demand and substitution theory, Alonso extended von Thünen's (1857) agricultural rent theory that portrays a monocentric market with concentric rings to the urban case and developed a general theory of land values and uses in cities. According to this theory, an individual householder trades off the size of the dwelling plot (residential density) against accessibility to the city center (or to the place of his employment), thus inducing bid-rent curves in a monocentric city model. While Alonso modeled the urban spatial structure in a framework in which individuals consume land directly, Muth and Mills further developed a more realistic monocentric model in which land is an intermediate input in producing houses (Brueckner, 1987). Nevertheless, these models assume that goods production only occurs in one contiguous area — CBD — by adapting the concept of agglomeration economies (Mills, 1967).

However, hardly can this monocentricity assumption be met in contemporary cities nor can the monocentric city model be held pervasively both in theory and reality, which induces the urgent need for fundamentally different models to depict the

changing urban spatial structure. First, the conflict between agglomeration economies and congestion arises from city expansion, which facilitates the emergence of employment subcenters that are radically against the monocentricity assumption (Anas, Arnott, & Small, 1998). Urban land use models are thus developed on the presumption that a city can constitute exogenously determined subcenters and the CBD. Accordingly, the land rent gradient shows a declining pattern from the CBD but an ascending trend to a local maximum at the subcenters, with a further fall beyond (Ross & Yinger, 1995; Sullivan, 1986; Wieand, 1987; Yang, French, Holt, & Zhang, 2012). Nevertheless, assuming *a priori* locations of employments is still condemned defective by some scholars who hold the view that a general equilibrium model should determine employment locations endogenously. Based on this view, non-monocentric city models are developed, in which multiple equilibriums can be yielded under different sets of parameter values (Anas & Kim, 1996; Fujita & Ogawa, 1982). Although these models either lack of theoretical derivations or have limited empirical verifications (McDonald & Prather, 1994; McMillen, 2001; Small & Song, 1994), they help to improve the understanding of how subcenters created by the spatial expansion of modern cities change the spatial layout of urban areas (White, 1999).

Second, the diversification ranging from commodities to city functions within a city gives rise to multiple centers for diversified activities, which makes the monocentricity assumption more untenable. Compared with the cities in the 20th century, contemporary cities are commonly characterized with the diversity of firm

types, the complexity of firm organizations, and the multiplicity of products. The demand for multiple centers within a city is thus stimulated by the varied location preferences of firms, units, and products (Hartwick & Hartwick, 1974; Ota & Fujita, 1993). An extended location model of a city with two developers is introduced as a response to this new demand emerging in the real world. According to this model, as a city increases in size, the business district would split in two — each with one developer — and the residential neighborhoods would correspondingly form new spatial patterns around the two centers (Henderson & Slade, 1993). A general location model of a city with multi-unit firms, where each firm consists of a front unit (e.g., business office) and a back unit (e.g., plant or back office), is further developed, in which a primary labor market emerges at the city center, whereas secondary labor markets are created in far suburbs (Ota & Fujita, 1993). Not only the production mode, but also the city functions that are used to be restricted to production, transportation, and housing in the monocentric city model are extended. Correspondingly, as each function tends to occupy its own premium location, ranging from the CBD for the financial function to amenities for the recreation function, fundamental changes in urban spatial structure are observed (Appold & Kasarda, 2013; Lee & Schuett, 2014). In line with the diversification of production system and city functions over the past decades, modern cities are increasingly filled by heterogeneous residents with different preferences (Anas et al., 1998). On the one hand, laborers with different education backgrounds, working skills, and posts of duty tend to set their own “business centers”, thereby

leading to multiple employment locations, around which bid-rent curves of corresponding laborers are formed (David & White Michelle, 1993; Helsley & Strange, 1990). On the other hand, the taste heterogeneity in housing conditions among householders decentralizes the linear urban form by “flattening” the rent and population density gradients, which makes the urban spatial structure in current cities more complex (Anas, 1990). Although most of the above models lack of simplicity and versatility in depicting urban spatial structure under various contexts compared with the monocentric city model (Baumont et al., 2004; McMillen, 2006; Spivey, 2008), they provide an enhanced knowledge of how subcenters generated by the functional diversification of modern cities transform the spatial layout in urban areas.

Despite the considerable efforts in modeling the spatial structure of cities with diversified functions and multiple centers, several problems remain unsolved in previous literature. First, various models are regarded as substitutions rather than complements to one another, with little consensus being reached on the most fitted model in cities with subcenters. Non-monocentric models criticize the monocentric one for being lack of contemporary values, while the monocentric model defends itself by its simplicity and versatility that non-monocentric ones are absent of. Second, theoretical models on urban spatial structure and empirical studies on urban space in contemporary cities have been conducted separately with limited research to apply a well-developed model in current polycentric cities. More importantly, in comparison with most cities in developed countries that have already experienced spatial expansion

and functional diversification, cities in developing countries, such as China, are currently undergoing the rapid urbanization with an increasing urban expansion and a significant functional change from production to consumption, leisure, culture, and so on (Mommaas, 2004; Zhou & Cao, 1999). These continuing dynamics in developing countries, which have been seldom studied, pose valuable resources for understanding the spatial structure changes in contemporary cities with the proliferation of centers and according adjustments of urban space. In addition, China, which is not only a typical case of continuous city expansion and dramatic functional diversification but also a post-Soviet country, has witnessed the breath-taking transformation of spatial morphology from the collage of homogeneous work-unit compounds that satisfy the socialist ideals of self-reliant and egalitarianism to a new pattern characterized by the differentiation of residential space and home–work separation (Hu & Kaplan, 2001; Wu & Yeh, 1999; Wu, 2005).

In this sense, probing into the urban spatial structure of Chinese cities with an intention to develop an integrated city model is not only applicable and appropriate but also has theoretical and practical significance. On the theoretical side, this study aims to develop an integrating rather than substituting model that possesses both the simplicity of the monocentric city model and the explanatory power of non-monocentric city models, thus linking the gap among various theoretical models. On the empirical side, by discerning the urban spatial structure in Haikou City in China, this study thoroughly applies a theoretical model to a typical city in a developing

country undergoing various transformations, which can further deepen and extend our understanding of the dynamics of urban spatial restructuring.

2.2. *Measures*

Two measures, namely, land price and the spatial concentration of urban population and employment, are widely used to explore the regularities and irregularities of urban spatial structure (Aguilar & Lozano, 2016; Anas et al., 1998; Ding & Zhao, 2014). Rent (or land value) is the most straightforward measure in that bid-rent curve is the spatial form of the monocentric city model. Assuming identical utility functions and a Pareto distribution of incomes, Beckmann (1969) found that rent turns out to be a power function of distance to the CBD in monocentric urban areas. McMillen (1996) discovered that Chicago was no longer a monocentric city by estimating the land value functions from 1960 to 1990. In a similar manner, land value has been extensively adopted as the measure of urban spatial structure over the past decades (Atack & Margo, 1998; Bender & Hwang, 1985; Haughwout, Orr, & Bedoll, 2008). Compared with the direct measure, the indirect measure — employment and population density gradient — is more universally employed because of its high availability and great convenience to match theory with empirical studies (Anas et al., 1998). Initiated by Clark (1951), this line of research has examined the changing spatial structure of cities in continental Europe and the United States (Garcia-López & Muñiz, 2010; McDonald & Prather, 1994; McMillen, 2001; Small & Song, 1994; Spivey, 2008).

However, the abovementioned two measures suffer significant deficiencies in

either practice or theory. Although land value data directly point to the bid-rent curves in urban spatial models, they are scarce and inconsistent over time in most practical cases. By contrast, employment and population density gradients, though are readily available in cities, are derivatives of the capital–land ratio — the key concept in bid-rent curves. However, the FAR, simply defined by building area divided by plot size (McMillen, 2006), is a measure that can be easily accessible without temporal incomparability in practice and simultaneously reflect the capital–land ratio concept directly in theory. Considering that the values of land closer to the city center — where transport costs are lower — are higher, the monocentric city model implies that firms would substitute more capital (structure) for land, thereby raising the FAR around the city center (O'Sullivan, 2011).

The direct literature on urban spatial structure based on FAR gradients is restricted, and limited works have contributed indirectly to the literature of FAR gradients by examining the intra-urban locations of tall buildings (Barr, 2012; Barr & Cohen, 2014; Clapp, 1980; Frenkel, 2007; McMillen, 2006). Yet, high-rise or commercial buildings only compose a minimal share of the total land in a city. The main composition and the target of urban spatial structure are housing locations; their FAR, however, is rarely analyzed because of the limited data sources. Therefore, apart from the abovementioned contributions in forming an integrated model to fill the gap among various theories and in examining the model in developing countries undergoing great urban transformations, this study further analyzes urban spatial structure directly and precisely by employing

an important, yet rarely investigated form of urban density — the FAR of residential land parcels.

3. Study area, data, and methods

3.1. Study area

This study considers Haikou City in China as the empirical case to achieve the above research purposes. Located at the north-most of the Hainan Island, Haikou occupies an area of 2305 km² with a total population of 2.22 million in 2015 (Hainan Statistical Bureau, 2016). As the provincial capital, Haikou is the political, economic, financial, and transportation center of Hainan Province, which is the south-most province, the only tropical province, and one of the five Special Economic Zones in China¹.

Specifically, the study area is the main urban area of Haikou City, which covers 119 km² (Figure 1). Compared with the administrative area that includes both urban and rural land, the main urban area in Haikou only contains urban land, on which commercial houses are exclusively allowed to be built (Zhou & Shi, 1995). Therefore, owing to the urban–rural dual land and housing system in Chinese context, the study area should be confined to the main urban area instead of the administrative area to produce unbiased results of the urban spatial structure.

¹ Special Economic Zones (SEZs) are at the forefront of the economic reforms in China since the 1980s. Among which, Hainan is the only provincial level and the largest one (others are Shenzhen, Zhuhai, Shantou within Guangzhou Province, and Xiamen in Fujian Province).

As the capital and the largest city in the Hainan Province, Haikou has been a traditional production city with accelerated economic growth in the past two decades. Meanwhile, against the backdrop of the spurring demand for tourism in mainland China in this century, the pleasant climate and abundant natural resources in Haikou have attracted tourists across the country. Consequently, Haikou has also become a famous tropical coast resort recently with a well-developed transportation system and high-quality public services (Xuan, Lu, Zhang, & Yang, 2002). Therefore, Haikou has experienced a significant functional diversification from a pure production city where the traditional production sector clusters at the city center to a hybrid production and consumption city where the additional tourism sector scatters along the coast. This diversification not only has contributed to the rapid expansion of the urban space in the city, but also might have changed its spatial structure from monocentricity to polycentricity. In this sense, Haikou City is a compelling example to understand the dynamic spatial structure in contemporary cities that are undergoing the proliferation of centers accompanying with the continuous spatial expansion and functional diversification.

Figure 1. Map of residential plot samples in the main urban area of Haikou, China.

3.2. Data

The data used in this study were collected jointly by Haikou Municipal Bureau of Land and Resources and Peking University in 2012. The residential plot samples in this data were attained through two steps. First, contiguous residential plots that were similar in land use function, land use intensity, and land value were merged, through which 290 residential function areas were generated. Second, at least one plot were selected in each residential function area, through which 328 residential plot samples were selected from 290 residential function areas. For every residential plot sample, extensive information, including address, FAR, building density, population density, plot size, and other data related to infrastructure, has been collected.

The work on measuring the nature of urban spatial structure tends to concentrate on density changes relative to the central core (Barr & Cohen, 2014). For this study, the location of the People's Government of Hainan Province is selected as the city center because it has long been the conjunction of various resources and concurrently

combined political and commercial powers. The coast is selected as the tourism “center” owing to the fastest rising status of coastal tourism in the tourism industry of Haikou (Figure 1). The distances to these two “centers” for each residential plot sample were calculated by ArcGIS10.2, respectively.

Our data set comprises 328 residential plot samples, with a total area of 23.9 km², which covers approximately 20% of the main urban area in Haikou. The average distance to the city center (DCC) and distance to the coast (DC) are 4.8 and 2.6 km, respectively, with an average FAR of 1.4 and an average building density of 23.9% (Table 1).

Table 1. Descriptive statistics for residential plot samples.

	Mean	Std. Dev.	Min	Max
Residential plot samples ($n = 328$)				
FAR	1.4	0.9	0.003	5.8
DCC (km)	4.8	3.3	0.6	18.1
DC (km)	2.6	3.0	0.1	15.9
Plot size (m^2)	72967.4	47479.0	5352.2	447386.0
Land value ($yuan$)	1954.0	1751.4	23.0	9764.0
Building density (%)	23.9	11.2	0.3	64.5

3.3. Methods

A simple single-explanatory variable function estimated by ordinary least squares (OLS) for its coefficient is commonly used to analyze urban spatial structure in extant literature (Atack & Margo, 1998; McMillen, 1996; McMillen, 2006; McMillen, 2010). This function, which is always in a negative exponential form, predicts that such variables as land values, population densities, and FAR monotonically decline with DCC (McMillen, 2010). However, the assumption of a constant gradient coefficient across space in OLS can lead to biased estimates or standard errors, considering that

gradients can change over space because of the unevenly distributed marginal effects exerted by centers (McMillen & Redfearn, 2010). The fixed coefficients held by OLS also can hardly capture the subtle movements of gradients and the complex nature of spatial structures (Barr & Cohen, 2014). Therefore, GWR, which estimates a separate coefficient for each observation by giving more weight to nearby observations, is employed in this study to further elucidate the monocentric “city” models formulated by OLS regressions. The estimating equation for FAR based on GWR is

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_{ik}(u_i, v_i)x_{ik} + \varepsilon_i,$$

where y_i is the dependent variable (FAR) for observation i ; u_i and v_i denote the geographic coordinates of observation i ; x_{ik} refers to the independent variables (distances to centers); $\beta_0(u_i, v_i)$ is the separate constant for observation i ; $\beta_{ik}(u_i, v_i)$ is the separate estimated parameter for observation i . $\beta_{ik}(u_i, v_i)$ is obtained by ArcGIS10.2 with the Akaike’s information criterion procedure, which was outlined in the paper of Brunsdon et al. (1998).

In the following two sections, two monocentric “city” models will be developed based on their corresponding city functions — production at the city center and tourism consumption along the coast. For each function, a basic monocentric “city” model that shows the general pattern is formulated firstly by the OLS method. These basic models are then extended with details that show the fineness of the urban spatial structure in these monocentric “city” models by using GWR.

4. Production function: monocentric “city” model around the city center

This section presents the monocentric “city” model formulated around the city center for its production function. The model proceeds as follows. The FAR gradient from OLS equations is presented first to examine the existence of a basic monocentric “city” model. This benchmark model is then extended by using the GWR method. Through this extending process, more detailed information on distance–FAR relationships, including the influencing area, the uneven effects over distance inside the area, and the asymmetrical effects on the inland and sea sides, is explored.

4.1. Basic monocentric “city” model around the city center

The nature of the FAR gradient from OLS equations is presented in Table 2. The distance gradient derived from a simple OLS regression in Eq. (1) exhibits an expected decline trend, i.e., on average, FAR falls by 15% per kilometer with DCC. This falling phenomenon is in accordance with the prediction of the monocentric city model that a drop in the FAR gradient can be found as transportation costs fall. Eq. (1) also shows that this single-explanatory variable function can explain approximately 27.1% of the variations in the FAR gradient across the main urban area. This explanatory power is higher than its counterparts in other cities, such as 15.1% in Chicago (McMillen, 2006), 26.0% in New York (Barr & Cohen, 2014), and 18.9% in Beijing (Ding & Zhao, 2014).

Eq. (2) and Eq. (3) provide additional sets of controls. The explanation ability is brought up to 28.9% in Eq. (2) by adding in the log of the plot size, which is also statistically significant in determining FAR. This significance, however, disappears

when the log of plot size squared is also included in Eq. (3). In general, the addition of controls does not change the statistical significance of DCC in FAR gradient, even though its absolute value is reduced slightly. These results demonstrate that in Haikou, a strong monocentric “city” model that can explain the overall urban spatial structure to a considerable extent has been developed around the city center, where production activities are concentrated.

Table 2. OLS regressions of the monocentric “city” model around the city center.

	(1)	(2)	(3)
DCC	-0.150 (-11.08) ***	-0.141 (-10.31) ***	-0.141 (-10.19) ***
Ln(Plot Size)		-0.213 (-2.99) ***	0.550 (0.39)
Ln(Plot Size) ²			-0.035 (-0.54)
Constant	0.804 (10.20) ***	3.102 (4.02) ***	-1.019 (-0.13)
# Observations	328	328	328
Adjusted R^2	0.271	0.289	0.287

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. t -value in parentheses. Dependent variable: $\ln(\text{FAR})$.

Nevertheless, this basic monocentric “city” model derived from the simple OLS regression oversimplifies the urban spatial structure with the assumption that all residential plots in the main urban area are equally influenced by the DCC. In reality, however, neither all residential plots are significantly affected by the city center nor the DCC exerts the same effect on every residential plot. Therefore, in the subsequent subsection, using GWR to capture more subtle variations underneath this basic monocentric “city” model gives us detailed information on its influencing area and spatially uneven effects.

4.2. *Details of the monocentric “city” model around the city center*

A GWR of FAR on a constant and the DCC is run by ArcGIS 10.2 in this subsection. The local pseudo t -values of distance coefficients in this regression are presented in Figure 2². Admittedly, these t -values in GWR results do not correspond with accurate and reliable confidence levels as those in OLS models do because of the repetitively use of units, unavoidable collinearity and spurious correlation, which are inherent imperfections of GWR model (Brunsdon, Fotheringham, & Charlton, 1999; Páez, Farber, & Wheeler, 2011; Wheeler, 2009; Yu, 2007). They could still be used to justify the possibility that a point is significantly influenced by the city center: a high pseudo t -value in absolute term for a specific observation implies a high possibility of a significant effect of DCC on its FAR. Therefore, the spatial variation of the impacts of DCC on FAR could be discerned by simply analyzing the distribution of its pseudo t -values. As indicated in Figure 2, pseudo t -values scatter within 7 km from the city center, while they concentrated at a low level beyond 7 km. This reveals a break-up of t -values at 7 km, beyond which FAR has a relatively limited possibility to change with the increase in DCC. Thus, the main influencing area of the monocentric “city” model around the city center can be roughly identified as within 7 km from it.

² The coefficient estimation in GWR does not output p -values. Therefore, corresponding pseudo t -values are used instead.

Figure 2. t -values of distance coefficients in GWR versus DCC.

The distance coefficients are further classified by their relative locations to the city center — either inland or sea. Several facts can thus be comprehended from the results presented in Figure 3. First, the overall pattern (both the inland and sea sides) shows that the coefficients close to the city center are small (in absolute value). As they move away, the coefficients become bigger (in absolute value), which means that the gradient steepens continuously outward within the main influencing area. This increasing trend of coefficients (in absolute value) also suggests that the FAR away from the city center is more sensitive to distance changes. Second, the different patterns of two sample groups signify the higher sensibility of the coefficient to the distance on the inland side than that on the sea side. In other words, the FAR on the inland side is more dependent on the city center than that on the sea side, which clearly indicates an asymmetrical urban spatial structure. Third, beyond the main influencing area, the coefficients on the sea side decline (in absolute value) steadily. This finding suggests the possible existence of another “center” along the coast that mediates the steepening trend of the FAR gradient. The influence of this potential “center” will be further discussed with another

monocentric “city” model in the following section.

Figure 3. Distance coefficients in GWR versus DCC.

5. Tourism consumption function: monocentric “city” model along the coast

This section presents the monocentric “city” model formulated along the coast for its tourism consumption function. Similar to the previous monocentric “city” model around the city center, simple regressions of $\ln(\text{FAR})$ on the DC by the OLS method are first presented. The GWR results are then shown to further elucidate the model with its influencing area and uneven effects over distance.

5.1. Basic monocentric “city” model along the coast

A simple single-explanatory distance gradient using the OLS method can be found in Eq. (1) of Table 3. This gradient, which is formulated along the coast, can explain 12.9% of the variations in the FAR gradient across the main urban area. This value is much lower than the single-explanatory distance gradient around the city center (27.1%). On average, FAR decreases roughly by 11% per kilometer with DC, which is also lower than the gradient of the city center model (15%). Considering that some

coastal height limitations from zoning may change the monocentric trait, an additional quadratic term of DC is added in Eq. (2) to examine the possible monocentricity of the model. The result shows that the distance coefficient becomes statistically insignificant when the quadratic term is added, thereby implying that a monocentric “city” model other than a non-monocentric “city” model is formulated under the effect of the tourism consumption function along the coast.

Furthermore, the explanatory power of the model is largely improved from 12.9% to 16.6% when the control variable — the log of the plot size — is included, as shown in Eq. (3). This figure is further brought up to 17.3% after the log of plot size squared is controlled in Eq. (4). Similar to the monocentric “city” model around the city center, DC remains statistically significant in all three models with a marginal decrease in absolute value. These results demonstrate that, in contrast with the city center, a weak monocentric “city” model that can only explain the local urban spatial structure to a limited extent has been formulated along the coast, where the tourism consumption is operated.

Table 3. OLS regressions of the monocentric “city” model long the coast.

	(1)	(2)	(3)	(4)
DC	-0.113 (-7.02) ***	0.0342 (0.79)	-0.104 (-6.54) ***	-0.106 (-6.70) ***
DC ²		-0.012 (-3.64) ***		
Ln(Plot Size)			-0.299 (-3.94) ***	2.669 (1.75) *
Ln(Plot Size) ²				-0.137 (-1.94) *
Constant	0.377 (5.88) ***	0.186 (2.28) **	3.648 (4.38) ***	-12.404 (-1.49)
# Observations	328	328	328	328
Adjusted R ²	0.129	0.160	0.166	0.173

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. t -value in parentheses. Dependent variable: $\ln(\text{FAR})$.

5.2. Details of the monocentric “city” model along the coast

Figure 4 shows the distance coefficients derived from GWR versus DC. Unlike the city center circled by plots, the coast is semi-circled by plots with another side facing the sea, where no plot is available to be influenced. Compared with the distance coefficients in the city center model, the overall coefficients in the coast model are considerably smaller (in absolute value). This result is in line with the abovementioned fact that the coast has a weaker effect on the urban spatial structure in comparison with the city center. In addition, inland plots, compared with seaside ones, are much more dependent on the city center, which indicates that their FAR variations can hardly be caused by the coast. Based on these evidences, barely can the influence of the coast cross the city center that is located at the distance of approximately 5 km from the coast to affect the FAR in the inland side. This limited influencing area can also be verified in Table 4, in which DC is statistically significant in determining the FAR of seaside plots whereas is not in deciding that of inland plots. Therefore, the one-side monocentric “city” model along the coast has an influencing area between the coast and the city center.

Table 4. OLS regressions by inland and seaside sample groups.

	Seaside plots		Inland plots	
	(1)	(2)	(3)	(4)
DC	-0.466 (-2.13) **	-0.409 (-1.91) *	-0.109 (-1.60)	-0.029 (-0.17)
DCC		-0.228 (-3.34) ***		-0.074 (-0.49)
Ln(Plot Size)	1.915 (6.78) ***	1.501 (4.96) ***	1.143 (3.33) ***	1.101 (3.10) ***
Constant	-6.512 (-7.37) ***	-4.236 (-3.85) ***	-3.969 (-3.20) ***	-3.936 (-3.16) ***
# Observations	210	210	118	118
Adjusted R^2	0.181	0.219	0.145	0.140

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. t -value in parentheses. Dependent variable: $\ln(\text{FAR})$.

Within its influencing area, obvious variations in the distance coefficients can scarcely be observed from Figure 4, pointing to a constant marginal effect exerted by the tourism consumption function along the coast. In sum, these results exhibit that the coast has a small but stable effect on the FAR within its influencing area (between the coast and the city center), which further verify the prior fact that the urban spatial structure has only been changed to a limited extent because the tourism consumption function in Haikou City remains at its initial stage.

Figure 4. Distance coefficients in GWR versus DC.

6. Depicting urban spatial structure by an integrated city model

6.1. Developing an integrated city model

Along with its economic reforms and rapid urbanization over the past decades, China has witnessed vigorous spatial expansion and dramatic functional diversification in cities. Consequently, the rise of multiple centers in response to these transformations has changed their urban spatial structure from monocentricity to polycentricity. In this sense, Haikou City, having experienced the urban transformation from a pure

production city to a hybrid production and consumption city, is a fitted case for developing an integrated city model to better understand the dynamic urban spatial structure in these cities.

Currently, the overall urban spatial structure of Haikou can no longer be fully depicted and explained by the monocentric city model as it is a diversified metropolis with two “centers” — the traditional center and the coast. Yet, two monocentric “city” models at local levels are formed according to its two distinct city functions. Based on its long-existing production function, a strong monocentric “city” model around the city center dominates most of its urban spatial structure with a widely dispersed influencing area, a spatially uneven effect over distance, and an asymmetrical effect between the inland and sea sides. While founded on its newly developed tourism consumption function, a weak monocentric “city” model along the coast changes its local urban spatial structure with a one-sided effect on the urban space, a limited influencing area, and a small but constant effect over distance. These two monocentric “city” models — old and new, strong and weak, broad and local, and uneven and even — jointly construct the urban spatial structure in Haikou City (Figure 5).

Therefore, an integrated city model, in which the monocentric city model is used as the basic unit, can be developed to understand the formation of the current urban space in Haikou City undergoing significant spatial expansion and functional diversification. Figure 5 illustrates how this integrated city model works in Haikou City. As the Alonso–Mills–Muth model predicted, the urban spatial structure is initially

formed gradually into a monocentric city model by the long-existing effect of the city center. In this model, householder trades off between dwelling plots (residential density) and commuting costs, thus forming FAR curves that stretch from the city center to about 7 km away from it. Another monocentric “city” model is then developed along the coast by the same mechanism as the tourism consumption function arises, though its influencing area is relatively limited. Similar to this new function being added to Haikou and the effect of the coast being put into Haikou, the monocentric “city” model along the coast is layered on the existed one around the city center without disturbing it. In this sense, the overall urban spatial structure in Haikou is a *de facto* integration of these two monocentric “city” models, in which the newly developed one is added to the previously existed one. By applying this integrated city model, the changing urban spatial structure in Haikou can be dynamically comprehended in a single model, even though it evolves from monocentricity to polycentricity.

Figure 5. Urban spatial structure explained by the integrated city model in Haikou City.

6.2. *Advantages of the integrated city model*

The integrated city model, in which new monocentric “city” models are added to the previous ones when new centers emerge from the diversification of city functions, has advantages over both the classical monocentric city model and the recently-developed polycentric city models. On the one hand, compared with the Alonso–Mills–Muth model that assumes a single center in a city, the integrated city model allows the

violation of this assumption, which is pervasive in current cities. Accordingly, its explanatory power and contemporary values are much higher than the classical ones (Table 5).

On the other hand, unlike polycentric city models, this integrated city model possesses the ability of discerning the varied and detailed effects exerted by different centers. Conventional polycentric city models are developed on the assumption that each particle is affected simultaneously by every center in a city. However, centers emerging in different times and holding different functions have their distinctive influential areas and ways of influence. In Haikou City, for example, some particles are only influenced by the city center, some are exclusively affected by the coast, and others receive the impacts from both the city center and the coast. Ignoring these differences would lead to biased estimates in polycentric city models. As Table 5 shows, the coefficient of DC (in absolute value) would be merely 0.045 in the polycentric city model because this model treats samples from both seaside and inland indifferently, even though the FAR of the latter are *de facto* irrelevant to the coast. Therefore, the integrated city model, by analyzing the impacts of each center separately, not only can avoid this bias, but also gives more detailed information on how different centers shape the overall urban spatial structure in different ways.

Another advantage of this integrated city model lies in its strong explanatory ability of spatial variations in FAR. Existing single-explanatory FAR functions estimated by OLS can only explain 15%, 12% and 26% in Chicago, Beijing and New

York, respectively (Barr & Cohen, 2014; Ding & Zhao, 2014; McMillen, 2006). This explanatory power in Chicago has been improved to 21% when a noticeable number of controls is considered (McMillen, 2006). In comparison, this integrated city model, although its overall explanatory power is unknown, can explain at least 33.4% of FAR variations as one of its monocentric “city” models has an adjusted R-square of 0.334. In other words, this integrated city model could help to gain a more precise and comprehensive understanding of urban spatial structure.

Table 5. Comparison of different models.

	Monocentric city model (OLS)		Polycentric city model (OLS)	Integrated city model (GWR)	
	City center	Coast		City center	Coast
DCC	-0.141 (-10.31) ***		-0.122 (-8.07) ***	Coefficients of DCC ranging from 0 to -0.257	Coefficients of DC ranging from -0.032 to -0.150 (exclude outliers)
DC		-0.104 (-6.54) ***	-0.045 (-2.81) ***		
Ln(Plot Size)	-0.213 (-2.99) ***	-0.299 (-3.94) ***	-0.203 (-2.88) ***		
Constant	3.102 (4.02) ***	3.648 (4.38) ***	3.021 (3.95) ***		
# Observations	328	328	328	328	328
Adjusted R^2	0.289	0.166	0.303	0.334	0.309

More importantly, this integrated city model reconciles the monocentric one with polycentric ones and provides a dynamic perspective to follow the evolving trajectory of urban spatial structure. In the prior literature, a monocentric urban space can only be depicted by the monocentric city model but not by the polycentric one, and *vice versa*. This integrated city model, by contrast, can illustrate urban spatial structure in various conditions — whether mono or poly centric — without switching to fundamentally different models. Therefore, it puts an end to the “either-or” debate on the monocentric city model and links the gap among various theoretical models. In addition, as the integrated city model places emphasis on integrating rather than replacing process

throughout the gradual formation and continuous evolution of urban space, it has the ability to trace the urban spatial structure in each historical phase and could also be extended to depict the changing urban space in the future.

7. Conclusion

Accompanied with the emergence of multiple centers in contemporary cities, a heated “either-or” debate currently exists on the capability of the monocentric city model to explain the urban spatial structure. Some fundamentally different models have even been proposed as substitutions of the classical monocentric city model against this backdrop. Nevertheless, the applicability of various spatial models has rarely been examined and compared with substantial empirical evidence. In this respect, this study develops a complementing integrated city model by using the monocentric city model as a basic unit to depict the urban spatial structure under multiple centers. Considering Haikou City in China as an empirical case and employing FAR as an effective but rarely investigated measure, this study illustrates how this integrated city model can be developed from the monocentric “city” models and applied in spatially and functionally expanding cities.

The spatial structure of Haikou City can be partitioned into two monocentric “city” models. On the one hand, stimulated by the long-existing production function in Haikou, the city center serves as the production “center” for a strong monocentric “city” model, in which FAR falls by 15% per kilometer with DCC on average. Further investigations by using GWR suggest that this monocentric “city” model has a main influencing area

of approximately 7 km from it with spatially uneven effects over distance. While moving away, the gradient becomes steeper. The GWR also reveals the spatially asymmetrical effects of this model between the inland and sea sides — plots on the inland side are more sensitive to distant changes. On the other hand, aroused with the newly developed tourism consumption function in Haikou, the coast functions as a consumption “center” for a weak monocentric “city” model, in which FAR constantly falls by 11% per kilometer with DC. The results from GWR also show that the monocentric “city” model along the coast can only influence an area as far as the city center, thereby verifying its limitations on shaping the overall urban spatial structure. Based on these two distinct functions in Haikou, two monocentric “city” models — old and new, strong and weak, broad and local, and uneven and even — accordingly emerge.

In Haikou City, these two monocentric “city” models are the basic units that form the integrated city model that can depict the urban spatial structure clearly and precisely. To be specific, the newly developed monocentric “city” model along the coast superposes on the previous one around the city center as Haikou expands from a pure production city to a hybrid production and consumption city. In this regard, by adding and layering various monocentric “city” models formulated around corresponding centers, the integrated city model can depict the dynamic urban spatial structure of cities from single to multiple centers as their functions evolve and expand. Therefore, it not only bridges various theoretical models that are used exclusively in their respective situations, but also is inclusive and extendable in analyzing the spatial structure of a

city that evolves gradually from monocentricity and polycentricity. In addition, this integrated city model, overcoming the deficiency of polycentric city models in separating the impacts of various centers, can discern their varied and detailed effects thoroughly, which further promotes its explanatory power and contemporary values in depicting current cities, especially those undergoing dramatic transformations and rapid urbanization in developing countries, such as Haikou City in this study.

Hitherto, this study fills four gaps in the existing research on urban spatial structure. First and foremost, the conflict between the classical monocentric city model and the contemporary non-monocentric city reality is reconciled by developing an integrated city model. Second, the lack of literature on applying an urban spatial model to a city in the real world is made up by the case study of Haikou City in China. Third, the dearth of studies on the urban spatial structure in developing countries undergoing great economic and urban transformations is complemented by this case. Fourth, an important but understudied form of urban density — FAR — is used to directly depict the urban spatial structure in this study.

While the feasibility and benefits of this integrated city model for understanding the urban spatial structure have been demonstrated in this study, cautions still need to be taken before the model is applied elsewhere. Given that the centers in this integrated city model are exogenously determined, a comprehensive knowledge about the spatial and functional evolution of a city is the prerequisite to use the model to depict and understand its spatial structure. This integrated city model also assumes the separate

operations of each function in a city without considering the functional interactions among various “centers.” Thus, additional attention needs to be paid to the mutual relationships of different functions in the city when employing this integrated model, which will be a potentially important improvement for our future works.

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