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Polycentric urban development and urban amenities: Evidence from Chinese cities

Mingshu Wang
University of Twente, The Netherlands

Abstract

The recent literature on the "consumer city" and the "love of variety" argues that the provision of urban amenities makes a city more attractive. Meanwhile, polycentric urban development has been highlighted by academics and policymakers as a sustainable urban development regime, although its purported benefits need to be further investigated. Against this background, this paper empirically examines the relationship between polycentricity and the provision of urban amenities in 309 Chinese cities. After controlling for the size, population density, wage, and human capital, this paper finds that a higher degree of intra-urban polycentricity is associated with a larger number of urban amenities. Additionally, when all the covariates above are held, a higher degree of intra-urban polycentricity is associated with a greater diversity of urban amenities. Robust checks show that these findings are consistent with different polycentricity indices and diversity measures. Finally, possible explanations of the relationship between intra-urban polycentricity and urban amenities are provided from both the producer and consumer perspectives.

Keywords

Polycentricity, urban amenities, consumer city, diversity, intra-urban, China

Introduction

The attractiveness of cities is a constant topic in urban planning and management. Economic geographers and urban economists have long been focusing on the producer side of cities, where the production structure and agglomeration economies are the

Corresponding author:
Mingshu Wang, Department of Geo-information Processing, Faculty of Geo-information Science and Earth Observation, University of Twente, Drienerlolaan 5, 7522 NB Enschede, The Netherlands.
Email: mingshu.wang@utwente.nl

causes of population growth and economic development (Rosenthal and Strange, 2004). Recently, the "consumer city" thesis (Glaeser et al., 2001) has driven an impetus to understand cities from the perspective of people, i.e. the consumers. Grounded on earlier theories on urban amenities (e.g. Graves, 1983; Roback, 1982), cities attract more consumers to live better than others, where the attractiveness is defined not only by urban agglomeration economies but also by urban amenities. Stylized facts have been found in the United States (Glaeser and Gottlieb, 2009; Partridge, 2010; Rust and Chung, 2006) and Europe (Garretsen and Marlet, 2017) that amenity-rich cities are more attractive and enjoy greater urban growth. A concept related to the consumer city is the "love of variety" (Dixit and Stiglitz, 1977; Krugman, 1993). Cities are attractive because they provide consumers with a large variety of goods and services. More recent work in economic geography and urban economics provides empirical evidence that consumption amenities, mainly local and non-tradable goods, are a significant driving force for people to live in US cities (Chen and Rosenthal, 2008; Glaeser, 2011; Lee, 2010). Importantly, goods and service providers in cities may face less direct price competition by differentiating their products (Mazzeo, 2002), which consequently increases the product variety in a city.

In urban studies and planning scholarship, sustainable urban development has been extensively studied through the lens of urban quality of life and competitiveness (Myers, 1988; Robert, 1999; Tweed and Sutherland, 2007). Recently, polycentricity has become an essential term both as an analytical framework and as part of normative spatial development policies around the world. While a recent meta-analysis reveals that polycentricity is a multiscalar and multifaceted construct (Van Meeteren et al., 2016), it usually refers to a more balanced urban system where there are multiple independent urban "centers" with a similar degree of "importance" (Kloosterman and Musterd, 2001). The advocacy of polycentricity by scholars and policymakers is primarily associated with its purported benefits of economic productivity (e.g. Meijers and Burger, 2010 in the United States, Wang et al., 2019; Zhang et al., 2017 in China) and environmental consequences (e.g. Burgalassi and Luzzati, 2015; Veneri, 2010 in Europe, Liu et al., 2020; Wang et al., 2017 in China), where the agglomeration economies are better achieved in a more balanced urban system (i.e. a more polycentric urban structure) rather than a hierarchical urban system (i.e. a less polycentric urban structure). While these studies explain the advantages of polycentricity from the production side, there is a shortage of relevant studies on the consumer side, such as the provision of urban amenities. For example, do polycentric cities provide more quantities of urban consumption amenities? Do they render a greater variety of urban consumption amenities?

To the best of our knowledge, the only two pieces of empirical studies exploring the relationship between polycentricity and urban amenities are based on the city-regions of the Netherlands (Burger et al., 2014; Meijers, 2008). While Meijers (2008) finds that polycentric urban regions are correlated with fewer advanced and rare high-level urban amenities, their association with the number of retail facilities depends on the dispersion of the city-region (Burger et al., 2014). Given the uniqueness of a Dutch city (Garretsen and Marlet, 2017) and the fact that polycentric urban regions represent only one subject of polycentricity at inter-urban scale (Van Meeteren et al., 2016), such findings may not hold in other contexts, for example, in the United States or China.

Towards the end of the last century, the concept of polycentricity was introduced to China (Cheng and Shaw, 2018). Some Chinese cities have adopted a polycentric urban development strategy as part of their master plans (e.g. the "peri-urban region" planning in Beijing (Zhao, 2013) and the "edge urban areas" in Guangzhou (Cheng et al., 2017)). Against this background, we aim to empirically analyze whether polycentric cities are more

attractive in China regarding the quantity and the variety of urban amenities. While urban amenities include broad coverage of commercial and community services, we mainly focus on consumption places (e.g. restaurants, retail stores, hotels, entertainment, and professional services) in this study. Accordingly, information about urban amenities was obtained from Dianping.com, which is the most extensive website of a city living guide in China and whose data have been increasingly used in urban research (e.g. Huang et al., 2019; Long and Huang, 2019; Zheng et al., 2017).

Our work builds on the polycentricity literature where the polycentric urban form has been envisioned and observed in the United States (Arribas-Bel and Sanz-Gracia, 2014), Europe (Hall and Pain, 2006), and China (Cheng and Shaw, 2018). More recently, Liu and Wang (2016) quantified the degree of intra-urban polycentricity of 318 Chinese cities, where they found over half of Chinese cities have developed a polycentric urban system, with at least two urban centers.

Our work also builds on the consumer city and the "love of variety" literature, which focuses on the emerging consumption choices in cities (Dixit and Stiglitz, 1977; Glaeser et al., 2001; Handbury and Weinstein, 2015). The emergence of multiple urban centers (of people and activities) in polycentric urban development has increased purchasing power . People in (or nearby) different urban centers will be more likely to dine out, have fun, and purchase goods and services in the (or to the closest) urban center. Most recently, Zheng et al. (2017) demonstrated that the industrial parks in the urban periphery have caused the emergence of the suburban "consumer city" in China. Furthermore, the density and variety of urban functions expressed by urban amenities are recognized as crucial factors in assessing urban vibrancy (Huang et al., 2019).

The rest of the paper is organized as follows. The following section presents the literature review and theoretical framework. In Section "Research design," we introduce research design, data, and empirical strategies. Section "Empirical results" demonstrates the results of our main findings and robustness checks, respectively. Lastly, we discuss and conclude in Section "Conclusion and discussions."

Literature review and theoretical framework

Despite the stretched concept of urban polycentricity, there have been observed priorities in intra-urban polycentricity research and its relation to the urban economic geography literature (Van Meeteren et al., 2016). Our literature review and theoretical framework depart from a brief introduction of intra-urban polycentricity in China and its relationship with a revisit of Central Place Theory. While the polycentric urban structure has been discussed from an equilibrium perspective (Glaeser and Kahn, 2004) with empirical evidence from the United States (Anas et al., 1998), South Korea (Sohn et al., 2004), and more recently China (Yang et al., 2019), we examine the rationale of the co-location of urban amenities from the producer and consumer sides, which helped us to formulate the two refutable hypotheses. Although urban amenities can include a variety of commercial and community services, the focus of this study rests on urban consumption places (i.e. restaurants, retail stores, hotels, entertainment, and professional services).

Intra-urban polycentricity in Chinese cities and the revisited Central Place Theory

Intra-urban polycentricity in China usually refers to the polycentric urban structure in a prefectural level city and above.[1] A prefectural level city usually comprises core urban districts and their surrounding region, which in turn contains districts, county-level cities,

counties, towns, and other sub-divisions. In other words, a Chinese city is often like a "metropolitan region" in the United States (Liu and Wang, 2016), which is different from a functional polycentric urban region in the European context (see Burger et al., 2014; Meijers, 2008 as examples). Based on Liu et al. (2018) and Wang et al. (2019), the degree of intra-urban polycentricity can be conceptualized as how balanced the population is distributed among different subdivisions of a city (i.e. urban centers). If the population distribution is more hierarchical in various urban centers within a city, the level of intra-urban polycentricity of that city is lower (Figure 1(a)). Conversely, a higher degree of intra-urban polycentricity corresponds to a more balanced distribution of population among urban centers (Figure 1(b)).

The highlight of "urban center" in intra-urban polycentricity is particularly relevant to the iconic Central Place Theory (Christaller, 1966), which delineates the relations between the distribution of people and the provision of goods and services (i.e., central functions). Christaller demonstrates the theory in two phases. The first phase discusses population distribution, the supply of central functions, and the central places accommodating such relationships (Christaller, [1933] 1966: 27–58). The second phase hypothesizes there is a hierarchical pattern of central places (Christaller [1933] 1966: 58–80). Despite the fact that Central Place Theory has continuously been revisited and reconstructed (e.g. Buursink, 1975, and more recently Van Meeteren and Poorthuis, 2018), there are two critical notations related to this study.

First, a central place is not necessarily a "city." It can be "any economic geographical pattern based on central-place notions" (Christaller [1933] 1966: 16–17, 139, 198). The Central Place Theory is about "the location of central functions, a partial theory of settlement structure" (Carol, 1960). An "urban center" is defined as a cluster of places where the population density is significantly higher than their surroundings (Liu and Wang, 2016; Wang et al., 2019), which provides demands for different urban amenities and opportunities for the supply of goods and services. To put it differently, an "urban center" can be conceptualized as a "central place." Second, the premise of a hierarchical pattern of central places can be relaxed. Part of the reason is that Christaller assumed "central places of a higher order also contain all the central functions of the lower orders" for the simplification of operationalization (Christaller [1933] 1966: 64). Christaller ([1933] 1966: 43, 50) explicitly mentions that people do not always go to the nearest center due to multipurpose shopping. Furthermore, a recent study completed by Van Meeteren and Poorthuis (2018), with similar

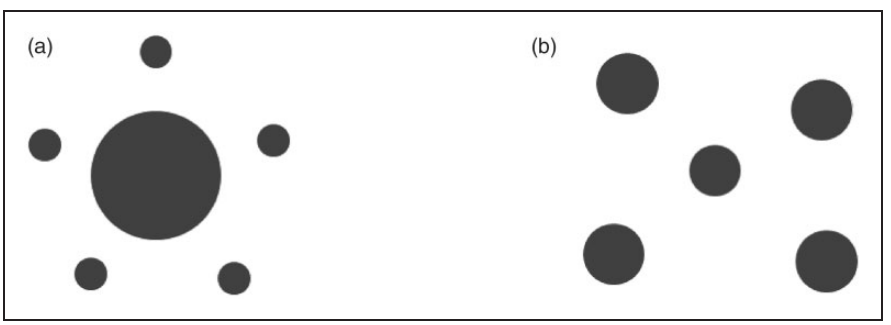

Figure 1. Conceptualization of intra-urban polycentricity. (a) Less intra-urban polycentricity. (b) More intra-urban polycentricity. Each circle refers to an urban center of a city; the relative size of the circle denotes the relative population size of that urban center.
Source: Adapted from Meijers and Burger (2010) and Wang et al. (2017).

volunteered geographical information data, relaxed the assumption that customers frequent the nearest urban center as well.

To sum up, on the one hand, multiple independent urban (population) centers provide more central places to supply different urban amenities for people. On the other hand, as people do not necessarily look for urban amenities in the nearest central place, more central places supply more opportunities for goods and services. Therefore, it is worth to explore further the relationship between central places represented by urban centers and the provision of urban amenities.

The co-location of urban amenities in urban centers: The producer side

Why firms are clustered is summarized by Ahlfeldt and Wendland (2012) regarding two forms of agglomeration economies from the production side, namely the first nature of geography and the second nature of geography. While the first nature of geography is more relevant to explain the natural comparative advantages of some locations for cities to emerge and subsequently for firms to cluster in the first place (Ellison and Glaeser, 1999), the externalities from the second nature of geography, where intense interactions between firms and consumers at the same location, are more pertinent to this study. The individual urban centers are arenas for such "interactions," and thus serve the function of central places.

First, the co-location of firms reduces transport costs through Marshallian externalities regarding resource sharing, labor pooling, and knowledge spillover in the labor market, which have been empirically tested (Ellison et al., 2010). Urban amenities relating to the service sector, such as restaurants, retail stores, entertainment establishments, hotels, and professional services, can save shipping costs when locating near to each other. Urban centers provide not only a vast customer base but also a large labor pool for firms in tertiary industries. Urban centers also create opportunities for intellectual spillovers from one firm to another firm. Second, the co-location of firms promotes innovation and more attractive cities through urban diversity, or Jacobs' externalities (Jacobs, 1969). Many urban inventions are crossover in nature, due to the stimulation of "ideas" in heterogeneous surroundings in cities. The emerging urban spaces of urban café and the food court in shopping complexes are just a couple of examples of these crossover innovations.

In theory, the externalities that one firm receives from the spatial closeness to others in a city can be found in any urban structure (regardless of the degree of intra-city polycentricity), based on the "locational potential function" by Fujita and Ogawa (1982). However, Helsley and Strange (1990) revealed that agglomeration economies are most influential within the central business district and decline with distance. Duranton and Overman (2005) further confirmed that such agglomeration effects are very localized at the zip code level. Therefore, the presence of multiple urban centers facilitates the emergence of central places, where those localized agglomeration economies can be potentially achieved in individual urban centers.

The co-location of urban amenities in urban centers: The consumer side

Urban amenities are location-sensitive, partly because of the nature of face-to-face transactions, for example, dining out, shopping in a mall, watching a show, and visiting a place. From a consumer's perspective, the various consumption demands are more likely to be realized in urban centers, where there are stores of various types and sizes. Urban centers are

areas with a significantly denser population, which can increase the consumption variety by spatially aggregating demand (Schiff, 2015).

First, consumers like the co-location of urban consumption spaces due to better service quality. For example, people like to dine out on a food street or the food court in a shopping complex, because it gives customers a variety of choices for catering. Importantly, the severe competition of co-locating restaurants benefits consumers because it ensures these restaurants provide quality food and services at affordable prices. Similarly, Larsson and Öner (2014) analyzed the co-location phenomenon of retail stores, in which urban centers are often occupied by either a cluster of small-scale stores or a large shopping center with nested shops.

Second, consumers like the co-location of urban consumption spaces due to multipurpose shopping trips. Since Christaller himself, it has been long documented that people prefer multipurpose shopping trips where they procure different types of goods and services (O'Kelly, 1981). An apparent reason is that a multipurpose shopping trip reduces the costs of time and travel. For example, on a typical weekend, friends may have brunch together in the morning, go shopping in retail stores in the afternoon, and have a drink in a bar in the evening. People will strategically select places that can satisfy the demand for multipurpose trips, i.e. where different kinds of urban amenities co-locate.

In a nutshell, the location-sensitive spatial demand of urban amenities favors urban centers with co-location of urban consumption spaces, which serve as central places. These central places also attract consumers in the surrounding areas.

Hypotheses

To summarize, urban centers are central places, which provide goods and services to people in and proximate to those centers through urban amenities (Section "Intra-urban polycentricity in Chinese cities and the revisited Central Place Theory"). From the producers' perspective, firms benefit from co-location in urban centers (i.e. Marshallian externalities and Jacobs' externalities) (Section "The co-location of urban amenities in urban centers: The producer side"). From the consumers' perspective, the spatially aggregating demand requires the co-location of urban consumption spaces (Section "The co-location of urban amenities in urban centers: The consumer side"). Given that urban amenities are location-sensitive, we formulate the following two hypotheses:

H1: A higher degree of intra-urban polycentricity is associated with a larger quantity of urban amenities.

H2: A high degree of intra-urban polycentricity is associated with a greater diversity of urban amenities.

Research design

We utilize multiple regression models to empirically test the relationship between intra-urban polycentricity and the provision of urban amenities (i.e. restaurants, retail stores, entertainment, tourist spots, hotels, and professional services) regarding their quantity and diversity in Chinese cities. In these models, the dependent variables are the total establishments of urban amenities (i.e. the quantity) and a suite of indices representing the extent of a variety of urban amenities (i.e. the diversity). The primary explanatory variable of

interest is the degree of intra-urban polycentricity, conceptualized via a morphological definition of polycentricity based on population distribution. We chose such a morphological perspective because of the following observations, which have been detailed in Liu and Wang (2016). First, focusing on population centers is relevant to Chinese urban planning and development practices. For example, one of the major planning goals in China is to shape the spatial distribution of the population. Relatedly, public resources and services are allocated on a per capita basis. Second, the gridded population data from LandScan not only provide us with population distribution information at fine granularity but also enable potential (international) comparison studies in the future. Nevertheless, we admit that the conceptualization and operationalization of polycentricity in this study is just one specific attempt of polycentricity measurement. Consequently, analyses based on other types of urban centers, such as employment (c.f. Meijers and Burger, 2010, for US cities and Li and Monzur, 2018, for Tokyo metropolitan region), may or may not reach the same conclusions.

Measures

First, we need to measure the *quantity* and *diversity* of urban amenities of each city, respectively. The *quantity* is a straightforward measure that calculates the totality of establishments of restaurants, retail, entertainment, tourist spots, hotels, and professional services. Regarding the *diversity*, we have utilized one well-established concentration index, namely the Herfindahl–Hirschman index (*HHI*). For robustness checks, we have also included two inequality indices as alternative measures for *diversity*, namely the Gini coefficient (*GINI*) and the Theil index (*THEIL*). While the formula of HHI is presented as follows, the definitions of *GINI* and *THEIL* are shown in the online Supplemental Material.

The *HHI* is computationally simple, which can be defined as the sum of all squared relative shares of urban amenities (equation (1))

$$HHI = \sum_{i=1}^{n} \left(\frac{UA_i}{\sum_{i=1}^{n} UA_i} \right)^2 \tag{1}$$

where for a city with n categories of urban amenities, UA_i denotes the sum of establishments of the ith urban amenities among restaurants, retail stores, hotels, entertainment, and professional services. *HHI* ranges from 0 to 1, where increases in the *HHI* indicate a decrease in diversity, where decreases suggest the opposite.

Second, we adapt the intra-urban polycentricity measure from Wang et al. (2017, 2019). The degree of intra-urban polycentricity (*POLY*) is modified from Meijers and Burger (2010), which computes the marginal effect of the rank-size distribution of the population in different urban centers within a city (equation (2))

$$POLY = \frac{\sum_{i=1}^{n} \sum (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{2}$$

where in a city with n urban centers, for the ith largest urban center, $x_i = \log_{10}(i + 0.5)$; y_i denotes the logarithm of the population with base 10; $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$; and $\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}$. The higher *POLY* is, the higher is the degree of intra-urban polycentricity in the city.

As a robustness check, another polycentricity index ($POLY^*$) adapted from Green (2007) is applied. This polycentricity measure examines the standard deviation of the size of urban centers (equation (3))

$$POLY^* = 1 - \frac{\sigma_{UC}}{\sigma_{\max_U C}} \tag{3}$$

where σ_{UC} denotes the standard deviation of the population among all urban centers in a given city and $\sigma_{\max_U C}$ denotes the standard deviation of the population in urban centers of a hypothetical two-center city where one center has "no population" and the other one has the "maximum" observed population in all urban centers of that city. $POLY^*$ ranges from 0 to 1, with a value of 0 denoting a total lack of intra-urban polycentricity within the corresponding city and 1 suggesting that the city consists of several urban centers of the same size. Like $POLY$, the higher $POLY^*$ is, the higher is the degree of intra-urban polycentricity in the city. While the formulae of $POLY$ and $POLY^*$ are different, these two polycentricity measures have produced similar results, with a correlation coefficient of 0.89.

Third, the following variables are included as control variables in the multiple regression, namely population, population density, wage, and human capital. Population ($POPULATION$) is measured by the resident population, which includes locals and seasonal immigrants. The inclusion of population is highlighted by the recent advancement of New Economic Geography (Ottaviano and Puga, 1998; Scott and Storper, 2003), in which agglomeration economies pivot on the population–development interactions. The consideration of "seasonal immigrants" is inspired by Puga (1999), which considers migration of labor forces as a vital factor of the self-reinforcing process of economic development. Furthermore, recent empirical work has shown that the industrial composition and the product diversity vary systematically with population size (e.g. Mori et al., 2008; Schiff, 2015). Population density ($DENSITY$) is measured by the resident population per square kilometer. In the "consumer city" article, Glaeser et al. (2001) speculate that higher population density may increase consumers' access to a variety of goods and services. Couture (2013) utilized Google Places and household travel survey data to reveal that increased population density enables consumers to realize gains from the variety. Additionally, Schiff (2015) found that the size and density of the population influence urban product variety. Wage level ($WAGE$) is measured by the average wage in a city. A growing number of firms spur competition, which increases the demand for labor and raises wages (Krugman, 1999). Human capital (HC) is measured by the number of people with a bachelor's degree and above. A high concentration of skilled workers provides knowledge spillover, which is an essential influencing factor of agglomeration economies (Fu, 2007). Relatedly, Florida (2002) found that human capital distribution, which he termed the "creative class" (Florida, 2014), is closely associated with urban amenities.

Data and study area

We obtained information on urban amenities from Dianping.com, the most extensive website of a city living guide in China, which provides merchant information on restaurants, retail stores, entertainment, tourist spots, hotels, and professional services for all Chinese cities. Despite the fact that Dianping has been widely applied as the data source for urban amenities in the urban planning/studies literature (e.g. Huang et al., 2019; Long and Huang, 2019; Zheng et al., 2017), there are two major advantages of Dianping, which are particularly relevant to this study. First, we are primarily interested in urban consumption spaces.

Rather than for all kinds of urban amenities, Dianping is dominated by restaurants, shops, and leisure services, which is precisely the focus of this study. Second, there are no significant competitors to Dianping in China, making it de facto the most comprehensive and representative data source—with coverage of all Chinese cities. A Python program was written to scrape the listing of establishments of urban amenities of all Chinese cities in 2015. The measurements of intra-urban polycentricity are based on LandScan^{TM}, which provides an estimation of the rasterized population at a 1 km spatial resolution. The identification of urban centers is obtained from Liu and Wang (2016). Accordingly, all control variables were populated from the China City Statistical Yearbook.

The analysis starts with all 364 mainland Chinese cities at the prefectural level and above. Despite the fact that there are 46 cities without urban centers with a "significant dense population", 9 cities without complete socioeconomic profiles to construct the set of control variables are further excluded. The final dataset covers 309 Chinese cities, which includes 22 provinces, 5 Autonomous Regions, and the 4 municipalities directly under the Central Government in Mainland China (Figure A1 in the Supplemental Material). Figure 2 shows the spatial distributions of the quantity and the diversity of urban amenities in the study area. Table 1 presents the descriptive statistics of all measures in the following empirical analysis.

Estimation strategies

The provision of urban amenities in Chinese cities is tested empirically through

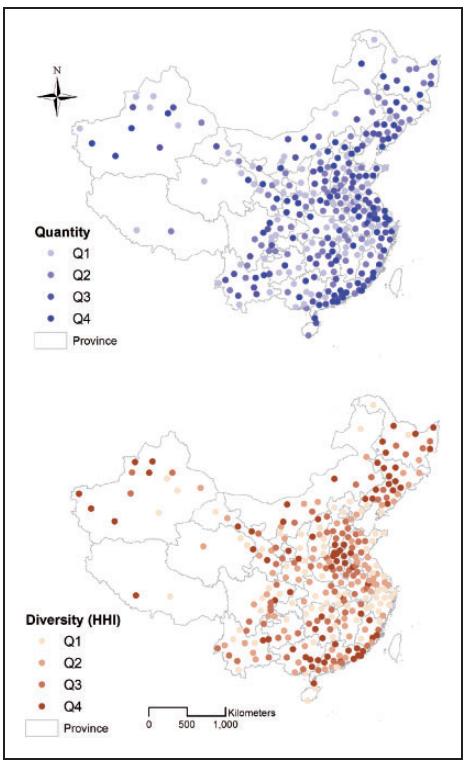

Figure 2. The distributions of the quantity and diversity of urban amenities. Q1 to Q4 represent the first, second, third, and fourth quantiles, respectively.

Table 1. Descriptive statistics of variables ($N = 309$).

Variable	Minimum	Maximum	Mean	Standard deviation
QUANTITY	2,072.000	714,172.000	59,123.960	79,820.810
HHI	0.068	0.203	0.145	0.021
POLY	–4.000[a]	–0.032	–2.237	1.541
*POLY**	0.000	0.965	0.225	0.246
Log (POPULATION)	3.153	7.775	5.782	0.746
Log (DENSITY)	0.416	8.572	5.502	1.244
Log (WAGE)	10.100	11.359	10.594	0.197
Log (HC)	–0.546	5.940	2.049	1.040
AVGS	0.016	10.323	2.214	1.829

[a]We assigned a *POLY* value of –4 to cities with only one urban center.
HHI; Herfindahl–Hirschman index.

multiple regression models in regard to intra-urban polycentricity based on the following set of linear models

$$QUANTITY = POLY + \log(POPULATION) + \log(DENSITY) + \log(WAGE) + \log(HC) + e \text{ (Model 1)}$$

$$DIVERSITY = POLY + \log(POPULATION) + \log(DENSITY) + \log(WAGE) + \log(HC) + e \text{ (Model 2)}$$

where e refers to the error term of the corresponding model. In Model 1, the dependent variable—the totality of urban amenities—is a count variable. Therefore, the relationship between intra-urban polycentricity and urban amenities is examined using a negative binomial regression model. For a robustness check, Model 1 is re-run by taking $\log(QUANTITY)$ as the dependent variable to fit an ordinary least square (OLS) model. In Model 2, *DIVERSITY* is proxied by *HHI* to fit an OLS estimator as our main model. For a robustness check, Model 2 is re-run by replacing *HHI* with *GINI* and then *THEIL*, respectively.

A critical concern of the regression model is the endogeneity problem, which often results from misspecification and a loop of causality between an explanatory variable and dependent variables. We adopted three strategies to handle this potential issue. First, we took an approximately two-year lag of data to construct all explanatory variables to address the reverse direction of causality partly. In other words, in Model 1 and Model 2, we regressed the provision of urban amenities in 2015 with the intra-urban polycentricity and other controlling factors in 2012. Second, we checked if multicollinearity exists in both models, given it is a common source of misspecification. The variance inflation factor (VIF) is commonly reported to reflect the severity of multicollinearity, where a VIF over 5 indicates the presence of multicollinearity (O'brien, 2007). Third, we applied two-stage least square (2SLS) regressions to Model 1 and Model 2 to further test and control for potential endogeneity. Following Wang et al. (2019), we utilized the average slope of the landscape ($AVGS$) for each city as the instrument for its intra-urban polycentricity. $AVGS$ is the first-order derivative of a digital elevation model (DEM), where global DEM data are available from the United States Geological Survey (https://doi.org/10.5066/F7DF6PQS). Natural landscape matters in determining intra-urban polycentricity, because mountains, waterways, and coastal lines delineate urban land use patterns. However, topographical features are unlikely to be correlated with the provision of urban amenities. Therefore,

$AVGS$ meets the requirement of an instrument, according to Wooldridge (2010). In the presence of endogeneity, OLS is biased and inconsistent; therefore, 2SLS should be preferred over OLS. Conversely, OLS is more efficient, which should be preferred. Lastly, we conducted an additional round of robustness checks by replacing $POLY$ with $POLY$* as the degree of intra-urban polycentricity and re-ran Model 1 and Model 2 to reflect the nuances of different measures. We present the regression results along with robustness checks in the next section.

Empirical results

Intra-urban polycentricity and the number of urban amenities

With a negative binomial estimation strategy, Table 2 shows the relationship between intra-urban polycentricity ($POLY$) and the number of urban amenities in a city, controlling for other city-specific features (Model 1). The likelihood ratio test was performed, resulting in a significant chi-square value ($p < 0.001$).Therefore, the negative binomial specification is better than a Poisson counterpart, due to the presence of over-dispersion. We also fitted Model 1 with an OLS estimator and its 2SLS counterpart, where $POLY$ is instrumented by $AVGS$. The weak instrument test was significant (14.967, $p < 0.001$), indicating that $AVGS$ is a valid instrument variable for $POLY$. However, the Wu–Hausman test is insignificant, suggesting that OLS is consistent, and endogeneity may not be a big problem. Therefore, we report the results of OLS in Table 2. Furthermore, the VIF test indicates that none of the explanatory variables has a VIF value greater than 5, indicating multicollinearity is not an issue in Model 1.

In Table 2, it is clear that the higher degree of intra-urban polycentricity is positively associated with the number of urban amenities, conditioning on other covariates, which is consistent with our proposition. Meanwhile, the negative binomial estimator and OLS produce similar estimation results. Based on the negative binomial model, if a city increases its intra-urban polycentricity degree by 1 point, the difference in the logs of the expected quantity of urban amenities would be expected to increase by 0.023 units, while holding the other

Table 2. Estimation results of the number of urban amenities (Model 1).

	Negative binomial			OLS		
	QUANTITY			*Log (QUANTITY)*		
Dependent variable	Estimate	SE		Estimate	SE	
(Intercept)	4.406	1.133	***	4.631	1.137	***
Log (POPULATION)	0.208	0.043	***	0.208	0.045	***
Log (DENSITY)	0.087	0.016	***	0.091	0.017	***
Log (WAGE)	0.327	0.096	***	0.299	0.098	**
Log (HC)	0.538	0.030	***	0.547	0.031	***
POLY	0.023	0.010	*	0.022	0.011	*
–2* log-likelihood	–6571.877			*N/A*		
Adjusted R^2	*N/A*			0.901		

Note:
SE represents heteroscedasticity-consistent standard errors.
Significant codes: ***0.001; **0.01; *0.05.
OLS: ordinary least squares.

covariates constant. In contrast, the log-level OLS regression is easier to comprehend. If a city increases its degree of intra-urban polycentricity by 1 unit, we would expect the number of urban amenities of that city to increase by 2.2%.

Intra-urban polycentricity and the diversity of urban amenities

Table 3 shows the results of the OLS and 2SLS estimation of intra-urban polycentricity (*POLY*) on the diversity of urban amenities in a city, measured by *HHI*. The weak instrument test was significant (14.970, $p < 0.001$), indicating that *AVGS* is a valid instrument variable for *POLY*. Furthermore, the Wu–Hausman test is significant (22.36, $p < 0.001$), suggesting the existence of endogeneity. Therefore, OLS is no longer consistent. Hence, a 2SLS estimator is preferred over an OLS estimator.

In Table 3, it is evident that after instrumentation, the degree of intra-urban polycentricity is positively correlated with the diversity of urban amenities, when other variables are constant, which is consistent with our proposition. After instrumentation, if we increase the degree of intra-urban polycentricity of a city by 1 point, we would expect the diversity of its urban amenities increases by 0.0168 units (a decrease of *HHI* indicates an increase of diversity).

Robustness checks

First, we re-ran the negative binomial specification of Model 1 by replacing *POLY* with *POLY**, an alternative measure of intra-urban polycentricity. Similarly, the likelihood ratio test with significant chi-square value ($p < 0.001$) indicates that the negative binomial specification is better than a Poisson counterpart due to the over-dispersed distribution of *QUANTITY*. The estimation results are consistent with Table 2; if a city increases the degree of its intra-urban polycentricity as defined by Liu and Wang (2016) by 1 unit, the difference in the logs of the expected quantity of urban amenities would be expected to increase by 0.116 units while holding the other explanatory variables constant.

Second, we re-ran Model 2 with both OLS and 2SLS estimators by replacing the diversity measure of urban amenities *HHI* with *GINI* and *THEIL*, respectively. The significant weak

Table 3. Estimation results of the diversity of urban amenities (Model 2).

	OLS			2SLS[a]		
Dependent variable: *HHI*	Estimate	SE		Estimate	SE	
(Intercept)	0.1102	0.0840		–0.1416	0.1599	
Log (POPULATION)	0.0087	0.0031	**	0.0257	0.0078	**
Log (DENSITY)	0.0019	0.0013		–0.0032	0.0025	
Log (WAGE)	–0.0006	0.0075		0.0137	0.0125	
Log (HC)	–0.0094	0.0019	***	–0.0131	0.0036	***
POLY	0.0001	0.0008		–0.0168	0.0060	**
Adjusted R^2	0.074			N/A		
Weak instruments	N/A			14.970		***
Wu–Hausman	N/A			22.36		***

Note:
SE represents heteroscedasticity-consistent standard errors.
Significant codes: ***0.001; **0.01; *0.05.
[a]The instrument of *AVGS* was applied in the first stage of the 2SLS regression for the endogenous variable *POLY*.
2SLS: two-stage least squares; OLS: ordinary least squares.

instruments and Wu–Hausman tests ($p < 0.001$) indicate the preference of 2SLS over OLS for both estimations. The results of the 2SLS model are consistent with those in Table 3, where an increase of intra-urban polycentricity is associated with a higher level of diversity of urban amenities in a city, measured by both *GINI* and *THEIL*. Furthermore, we re-ran Model 2 by replacing *POLY* with *POLY** with both OLS and 2SLS, with all three urban amenity diversity measures as dependent variables. The findings are consistent with Table 3.

Conclusion and discussions

In this study, we have explored the relationship between intra-urban polycentricity and the provision of urban amenities in 309 Chinese cities. It is found that a higher level of intra-urban polycentricity is associated with more quantity and greater diversity of urban amenities. Such a finding is robust to (1) different estimation strategies, (2) different indices of intra-urban polycentricity, and (3) different measures of the diversity of urban amenities. The finding has the following implications for the literature and urban development strategies.

First, the ultimate goal of sustainable urban development is to increase the quality of life of its citizen. Urban amenities play a critical role in attracting consumers to live and work. To put it differently, cities can benefit from the richness of urban amenities for their growth (Garretsen and Marlet, 2017; Glaeser and Gottlieb, 2009; Partridge, 2010; Rust and Chung, 2006). Our finding suggests that polycentricity is attractive for its positive correlation with both the quantity and the diversity of urban amenities at the city level in China. Firstly, the essence of intra-urban polycentricity is the emergence of multiple independent urban centers in a city. As we re-interpreted the classic Central Place Theory, these "urban centers" are conceptualized as "central places," which provide goods and services (i.e. central functions) through urban amenities. Secondly, the co-location of firms (urban amenities) in and close to those "urban centers" has been jointly explained by agglomeration economies from the producer side and spatial clustered demands from the consumer side. A firm that co-locates with other firms increases both the number and the diversity of urban amenities.

Second, our finding contributes to both fields of economic geography and urban economics regarding the "consumer city" (Glaeser, 2011; Glaeser et al., 2001) and the "love of variety" literature (Dixit and Stiglitz, 1977; Krugman, 1993). While most previous studies are based on US cities (Chen and Rosenthal, 2008; Glaeser, 2011; Lee, 2010), our work contributes to the strand of literature by providing empirical evidence in Chinese cities. Meanwhile, we also contribute to the polycentric urban development literature, which traditionally attributes the benefits of polycentric urban development to the facilitation of agglomeration economies from the side of production (Parr, 2004). Through the lens of urban amenities, we have expanded the potential benefits of urban polycentricity from both production and consumption perspectives, evident by a Chinese case.

Third, in addition to intra-urban polycentricity, this study finds that the stock of human capital is positively correlated with both the quantity and the diversity of urban amenities. Such a finding is supported by the "creative class" argument (Florida, 2002, 2014), where urban amenities rather than agglomeration economies attract creative people. Similarly, entrepreneurs in the creative industry consider urban amenities to be more critical than agglomeration economies for their location decision (Wenting et al., 2011). Relatedly, the population size is positively associated with the quantity but negatively associated with the diversity of urban amenities. As both the quantity and the diversity of urban amenities matter in modern cities, one policy implication is that when the total population of a city is held, the city may be better off to distribute people amongst multiple urban centers.

Nevertheless, Wang et al. (2019) have revealed a mixed relationship between polycentricity and urban economic performance, and the relation between economic growth and urban amenities has been discussed extensively in the literature. It is worth exploring possible paths among the nexus of polycentricity, economic growth, and urban amenities in the future.

Last but not least, some limitations of this work also set paths for future research. Firstly, the revisit of Central Place Theory in this study has relaxed the assumption of the hierarchy of central places for operationalization purposes. It will be worth to explore the role of polycentricity in different hierarchies of the central functions of urban amenities. Relatedly, this study ignores the size and level of each amenity facility. Information on the capacities and levels of different urban amenities may reflect more nuanced knowledge about the relationship between polycentric urban structure and urban amenities (e.g. Meijers, 2008). Secondly, this study represents only one specific attempt to measure intra-urban polycentricity. As polycentricity is a multiscalar and multifaceted concept (Van Meeteren et al., 2016), polycentricity metrics will inevitably be affected by the definition, scale, and data sources. Nevertheless, comparisons of polycentricity at various scales and different settings will provide a comprehensive view of polycentric urban development and a holistic perspective of its relationship with urban amenitie

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ORCID iD


Mingshu Wang https://orcid.org/0000-0001-5260-3143

Supplemental material

Supplemental material for this article is available online.

Note

1. In the Chinese administrative division system, a prefectural level city (*di ji shi*) ranks below a provincial-level unit but above county-level units. The "above" here explicitly refers to the four municipalities under the direct control of the central government (i.e. Beijing, Tianjin, Shanghai, and Chongqing).

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Mingshu Wang is a tenure-track Assistant Professor at the Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, The Netherlands. His research focuses on developing and applying methods of GIScience and big data analytics to understand urban systems and development. He received the Regional Science Association International (RSAI) Dissertation Award (2019), Netherlands Center for Geodesy and Geoinformatics (NCG) Talent Program Award (2019), and American Society for Photogrammetry and Remote Sensing (ASPRS) Robert N. Colwell Memorial Fellowship (2018). He is the Secretary of the IoTs and Spatial Decision Support Working Group of the International Society for Photogrammetry and Remote Sensing (ISPRS).