

Article

The Typology of Urban Polycentricity: A Comparative Study of Firm Distribution in 35 Chinese Cities

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Abstract

Prevailing theories and empirical studies have suggested that the internal spatial structures of large cities have transformed from monocentric to polycentric. However, the existing literature primarily focuses on the definition, measurement, and quantity of the urban centers, with a lack of in-depth comparison of urban polycentricity in terms of dynamic centralization or dispersion. By analyzing the spatial distribution of firms in 35 large Chinese cities, this study examines the quantity, centralization degree, and primacy ratio of urban centers to compare spatial structure of the cities and explores the different types of urban polycentricity by employing nonparametric regression methods. The findings indicate that the spatial structures of most cities are polycentric forms, which display three types: emerging polycentricity, centralized polycentricity, and dispersed polycentricity. Further analyses suggest that social and economic factors such as GDP and population size are associated with the typology. Through the comparison of the 35 cities' spatial structures, this study identifies three types of urban polycentricity and sheds light on the underlying forces of urban spatial restructuring process.

Keywords: urban spatial structure; firm distribution; polycentric structure; centralization degree; primacy ratio; Chinese cities



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1. Introduction

As transportation develops and information technologies proliferate, cities worldwide have undergone adjustments and reorganization in their spatial structures [1–5]. The internal spatial structures of many large cities, exemplified by some American cities, display characteristics of suburbanization, “new suburbanization”, and polycentricity [6–8]. Many of the dynamics in urban spatial restructuring can be observed in the concentration and dispersal processes [9]. A continuous dispersal of metropolitan population, manufacturing plants, retail jobs, and offices has occurred over the last century in most developed countries [10]. Meanwhile, the relocation of high-order services and head offices shows a new form of (re)concentration involving not only the central city, but also the emerging suburban centers, pushing cities from monocentric to polycentric layouts [11,12].

In urban China, recent studies have also documented a growing trend toward polycentric spatial restructuring in major cities. These works highlight the emergence of functional subcenters, the complex effects of socioeconomic factors, and the varied degrees of poly-

centricity across cities [13–15]. This evolving body of research reinforces the need for more refined studies on the typology of intra-urban spatial structures.

The extant empirical observations on and theoretical explanations of the evolution of urban spatial structures from monocentric to polycentric have largely focused on defining, identifying, and quantifying centers in analyses of polycentric urban structures [16–18], and they often treat the emerging urban centers as effectively identical to each other. Moreover, while such studies have improved our understanding of polycentric structures, they often pay limited attention to the internal mechanisms through which these structures evolve, particularly the role of agglomeration and dispersion over time. We seek to move beyond the conventional binary categorization of “monocentric” and “polycentric” and examine the typology of urban polycentricity through the lenses of “agglomeration” and “dispersion”.

Specifically, this study addresses the research question—how do different configurations of agglomeration and dispersion result in distinct forms of urban polycentricity across Chinese large cities? Rather than focusing solely on the number of centers, we emphasize the underlying forces of centralization and dispersion to construct a typology that reflects the heterogeneity of intra-urban spatial organization. This typological approach, grounded in firm distribution data, allows us to better understand the dynamics of urban spatial restructuring.

The extant researches on urban spatial structure in China largely rely on population data [5,16,19]. However, studies have shown that economic activity data are more effective than population data in capturing the spatial characteristics of urban structures [20]. Furthermore, differences in industrial structures, as reflected by various economic activity data, have been regarded as important factors contributing to the evolution of urban spatial structure [21,22].

Since the reform and opening up of China in 1978, there have been significant changes in the internal spatial structure of Chinese cities [23,24]. The dispersal of population and manufacturing is documented and confirmed in both English- and Chinese-language scholarship [25,26]. Emerging central business districts (CBDs) have gradually replaced the socialist urban spatial form characterized by the working unit (*danwei*) system, and some large cities have also developed polycentric spatial structures [27,28].

Cross-city comparative studies are essential to better understand polycentric urban structures and the underlying factors contributing to the structure [13,14,29]. Empirical research on the internal spatial structure of cities frequently employs population, employment, and firm statistics. However, because of the relative difficulties in acquiring employment and firm data in China [18,24,30], most comparative studies depend primarily on population-related spatial distribution data [13,16,31]. Nonetheless, at the core of urban spatial structure is the location of firms, not only because they are fundamental elements in the cities, but also because they exert direct influence on the spatial distribution of employment, population, land-use, public facilities, etc. [20]. “An important source of current change in urban structure is the changing economic relationships within and between firms” [12].

This study intends to compare and understand the urban internal spatial structures of 35 large Chinese cities, utilizing firm spatial distribution data to analyze, measure, and compare the characteristics of spatial structures via three indicators: the number of centers, the degree of centralization, and the primacy ratio. It further investigates the differences in the typology of polycentric structures and explores the factors associated with the typology.

2. Materials and Methods

This study examined the urban districts of 35 major Chinese cities (Figure 1), encompassing four provincial-level municipalities (Beijing, Tianjin, Shanghai, and Chongqing), 26

provincial/autonomous regions' capital cities (excluding Lhasa owing to its mismatched city scale), and five sub-provincial level cities (Dalian, Qingdao, Ningbo, Xiamen, and Shenzhen). These 35 major cities have large populations and are relatively advanced though, by no means, uniform economic development. Thus, they are frequently utilized as the study area for comparative works [32,33]. They represent China's largest metropolitan areas and include key nodes in the national urban system, such as municipalities, provincial capitals, and major sub-provincial cities. These cities have been focal points in recent national spatial development strategies. Compared with smaller cities, large cities are more suitable for conducting typological analysis due to their scale and urban functions. This selection helps ensure analytical consistency and interpretive clarity. As the definition of "urban area" in China is complicated and, to some extent, subjective, we use the officially defined urban district (shi qu) as urban areas for these cities in the study.

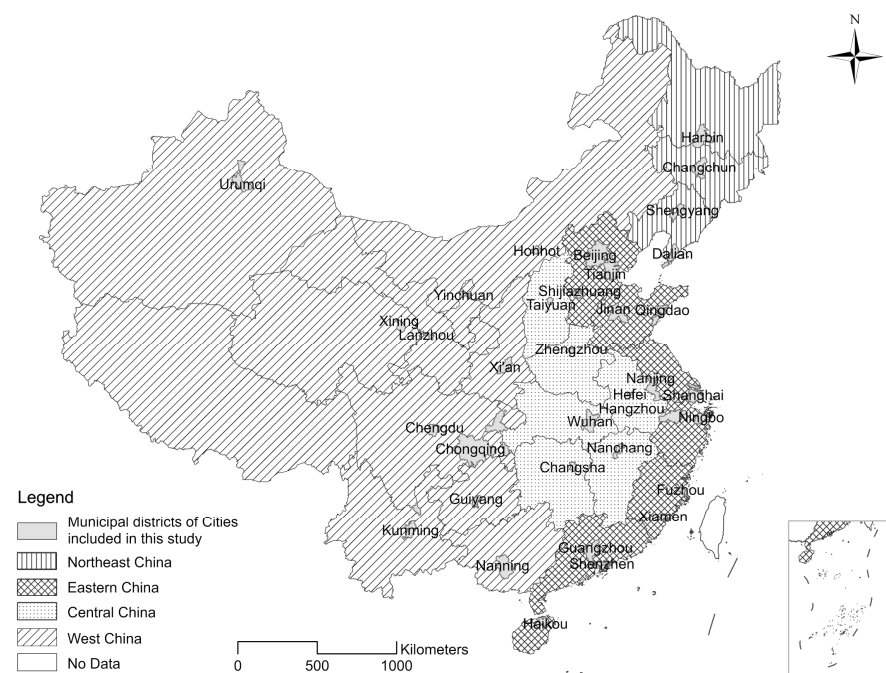


Figure 1. Study area. Notes: The four primary regions (northeast, east, central, and west) were defined during the 11th Five-Year Plan in 2006 [32].

2.1. Data Acquisition

The data for this study were obtained from the Tianyancha website (<https://www.tianyancha.com/> (accessed on 14 June 2025)), which offers comprehensive and accurate information on firms such as company name, type, registered address, industry category, registered capital, establishment date, business scope, etc. As of January 2022, 36.26 million firm-related data entries were collected from the urban districts of the 35 major cities (Table 1). After downloading, organizing, and cleaning the data, we converted the company address information into spatial coordinates using the Baidu API interface, creating a spatial database for firms in these 35 cities.

The dataset covers the majority of formal economic sectors but may underestimate informal economic activities. It may include outdated registration information. To ensure the accuracy of the Tianyancha data, we compared it to the firm data published by the Market Supervision and Administration Bureaus of 35 cities. The total number of firms in both datasets was largely consistent. Though accurate employment data would be better than the Tianyancha firm data, this is either not available or not accessible for Chinese cities.

Table 1. Number of firms within the administrative districts of 35 major cities.

City	Number of Firms (1000)	City	Number of Firms (1000)
Shenzhen	3247	Shenyang	697
Shanghai	2931	Dalian	639
Guangzhou	2810	Shijiazhuang	603
Chengdu	2437	Guiyang	593
Beijing	2140	Haikou	567
Xi'an	1782	Kunming	559
Chongqing	1645	Fuzhou	536
Wuhan	1437	Nanning	508
Tianjin	1350	Ningbo	500
Nanjing	1323	Taiyuan	499
Hangzhou	1269	Xiamen	421
Qingdao	1165	Urumqi	395
Jinan	1139	Yinchuan	248
Zhengzhou	864	Hohhot	231
Changsha	849	Xining	191
Changchun	815	Lanzhou	187
Hefei	784	Nanchang	154
Harbin	747		
Total		36,264	

Administrative divisions and other geographic data used in this study were collected from the National Basic Geographic Information Center (<http://www.ngcc.cn> (accessed on 14 June 2025)). Socioeconomic data were obtained from the Urban Construction Statistical Yearbook (2019) and other official statistical yearbooks. Data processing and calculation of the related indicators involved in the study were primarily conducted using the ArcGIS Pro3.0 software.

2.2. Methodology

2.2.1. Urban Center Identification

Identifying urban centers is essential for analyzing and examining urban internal spatial structures. To ensure conceptual clarity and terminological consistency throughout the paper, we use the following definitions: all spatial clusters of firms identified through our center recognition procedure are referred to as “urban centers”. Among them, the cluster with the largest number of firms is designated as the “primary center”, while all other clusters are uniformly termed “subcenters”.

Drawing on the existing literature on the definitions of population centers and employment cores, urban centers were characterized as regions comprising continuous spatial units with notably higher firm density than their surrounding areas and exhibiting both scale and spillover effects [34,35]. The primary steps to identify urban centers are outlined as follows:

- (1) Examining spatial clusters: A 1 km × 1 km grid was employed to divide the spatial scale of the 35 cities, as illustrated in Figure 2a. This scale division is widely used in urban geography and economics to represent the spatial distribution of urban economic activity [13,24].

To explore spatial clustering of firm activity, we applied Local Indicators of Spatial Association (LISA) [36]. Unlike the global Moran’s I that provides a single measure for the entire area, LISA evaluates each spatial unit individually to detect localized clustering. It could identify whether a specific grid cell is surrounded by similarly high or low firm density, thus offering a more nuanced view of spatial structure.

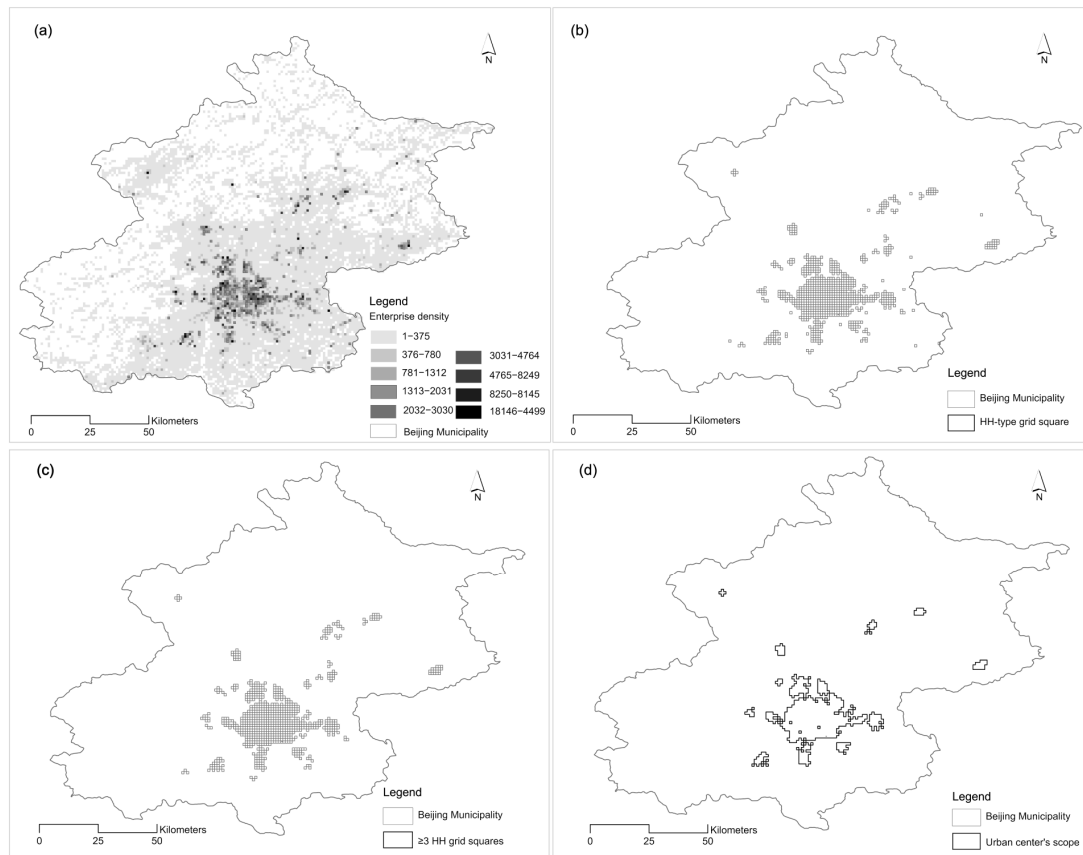


Figure 2. (a) Spatial distribution of firm density in Beijing by 1 km × 1 km grid; (b) HH-type grid square clusters by using LISA; (c) areas with three or more HH-type grid square clusters; (d) the identification results for the primary center and subcenters of firms in Beijing.

We applied the local Moran's I to identify spatial clusters of firms, as shown in Equation (1):

$$I_i = \frac{x_i - \bar{x}}{\sigma^2} \sum_{j=1, j \neq i}^n [w_{ij}(x_j - \bar{x})] \quad (1)$$

where I_i is the LISA statistic for grid cell i ; x_i is the firm density of the grid square i ; x_j is the firm density of neighboring cell j (where $j \neq i$); $\bar{x}$ represents the mean value of firm density for all grid squares within the city; σ^2 represents the variance of firm density for all grid squares within the city; and W_{ij} is the spatial weight between grid squares i and j .

- (2) Screening potential centers. To minimize the subjective bias arising from artificially defining the scope of subcenters, we employed 499 random permutations, specifically selecting grids with LISA values that were statistically significant at the 95% confidence interval [37,38]. The grid squares were divided into four categories: (1) high firm-density grid squares surrounded by high-density grid squares (HH); (2) low firm-density grid squares surrounded by low-density grid squares (LL); (3) high firm-density grid squares surrounded by low-density grid squares (HL); and (4) low-density firm grid squares surrounded by high-density grid squares (LH). Following the definition of urban centers used in this study, HH-type grid squares were retained as potential firm centers. Based on the criterion that urban centers should form a continuous area, HH-type grid squares with adjacent edges were screened using the vehicle adjacency principle (Figure 2b).
- (3) Defining the scope of the urban center. In this study, we adopt a threshold-based method to delineate the spatial extent of urban centers. This approach is widely used in similar research due to its advantages in consistency, repeatability, and operational

simplicity [18,34,39]. Regarding the specific threshold, we refer to benchmark values employed in the literature for identifying employment centers (see Table 2). A threshold of 10 jobs per hectare and a minimum of 10,000 total jobs has commonly been used to define employment centers, with later studies refining this by including labor-force ratios [20,40–43].

Table 2. Thresholds for Urban Center Identification in Existing Studies.

Author	Year	Study Area	Threshold Definition
Giuliano et al.	1991	1980 Los Angeles	≥ 10 jobs/acre and $\geq 10,000$ total employment [20]
Coffey et al.	2002	1981–1996 Montreal suburbs	≥ 5000 jobs + job/labor ratio > 1.0 [40]
Shearmur et al.	2003	1978, 1994 Paris	≥ 5000 jobs, working population mostly residents [41]
Giuliano et al.	2019	1980–2010 Los Angeles	Top 5% job density and $\geq 10,000$ jobs (Type I); top 1% density and $\geq 20,000$ jobs (Type II) [42]
Giuliano et al.	2022	1980–2009 Four U.S. metropolitan areas	Top 5% and 1% job density percentiles, plus job count thresholds [43]
Jiang et al.	2009	2004 Guangzhou	Sucenters: >5000 jobs/km ² (excluding parks) [44]
Zeng et al.	2010	2001, 2004 Shenzhen	Primary centers: $>30,000$ jobs/km ² and $>200,000$ jobs; subcenters: $16,000$ – $30,000$ jobs/km ² , $\geq 70,000$ jobs [45]
Zhang et al.	2019	2004, 2008, 2013 Shanghai	Two times the average number of employed people per grid (1 km ² , 5 km ²) [24]
Sun et al.	2020	2008, 287 Chinese cities	Job count $> 20,000$; residual exceeds 5% significance over zero baseline [30]

In China, no unified standard exists. Prior studies have used thresholds ranging from 20,000 to 200,000 total jobs and 5000 to 30,000 jobs/km², often focusing on megacities like Beijing and Shanghai [24,44,45]. Cross-city comparative work remains limited.

Building on this literature, we define an urban center as a contiguous cluster of at least three high-density grid squares (see Figure 2c) with a total firm count of no less than 10,000. This threshold balances spatial and economic significance while ensuring comparability across the 35 large cities. To test robustness, we also applied a 15,000-firm threshold (see Appendix A), with consistent results supporting the stability of this approach. Figure 2d illustrates the identified center boundaries.

Using the methods mentioned above, we identified the urban firm centers of the 35 cities, including the primary and subcenters, and summarized the grids in each firm center to calculate the total number of firms.

2.2.2. Comparison Indicators

Using the methods mentioned above, we identified the urban firm centers of the 35 cities, including the primary and subcenters, and summarized the grids in each firm center to calculate the total number of firms. In addition to the widely employed indicator of the number of centers, two other indicators—the centralization degree and primacy ratio—were used to comparatively analyze the polycentric structure of the 35 cities. The degree of centralization denotes the extent of agglomeration of various elements (i.e., firms) within a polycentric city, whereas the primacy ratio signifies the degree of agglomeration of these elements in the primary center of a polycentric urban structure [17,46,47]. Drawing an analogy between the relationship of multiple centers to cities and that of cities to regions, the degree of centralization resembles the degree of urbanization, and the primacy ratio parallels the degree of urban primacy in a region. Together, these three indicators enable a more comprehensive description of the agglomeration and dispersion patterns of various elements in urban center systems [48,49].

The centralization degree (*Cent*) represents the extent to how firms are centralized in the urban centers. This metric is determined by calculating the ratio of the number of firms in the city's center(s) to the total number of firms in the city [13,50]. The degree of centralization (*Cent*) is calculated using Equation (2):

$$Cent = \frac{Firm_{center}}{Firm_{total}} \quad (2)$$

Defined on a scale of 0 to 1, a higher value indicates a greater degree of centralization of elements within the urban centers.

The primacy ratio (*Prim*) is determined by calculating the ratio of the number of firms in the primary urban center to the number of firms in all urban centers [1]. This metric highlights the significance of the primary center within the urban system and is calculated using Equation (3):

$$Prim = \frac{Firm_{maincenter}}{Firm_{subcenter} + Firm_{maincenter}} \quad (3)$$

According to this definition, the value ranges from 0 to 1. A higher value indicates a greater degree of agglomeration of the primary center elements within the urban center system.

While both indicators reflect aspects of spatial concentration, they capture distinct features of polycentric structure. Centralization measures the overall extent to which firms are concentrated in all urban centers relative to the city as a whole, reflecting the cumulative intensity of central locations. In contrast, primacy highlights the dominance of the primary center compared to all centers, capturing the internal balance within the urban center system. Therefore, a city may exhibit high centralization if most firms are located in designated centers, even if these firms are evenly distributed across multiple centers—resulting in a low primacy ratio.

It is hypothesized that, when a city transforms from a monocentric to a polycentric structure, the degree of centralization will exhibit a pattern of initially decreasing, then increasing, and ultimately decreasing, whereas the primacy ratio consistently declines. In contrast to the fluctuating degree of centralization of urban center(s) during urban polycentric development, the primacy ratio exhibited a relatively stable downward trend. This is because both the formation of subcenters and the further dispersion of firms throughout non-central areas contribute to the decrease in the primacy ratio of the primary center.

2.2.3. LOWESS

To further examine the associations between various urban development factors and the comparison indicators, the Locally Weighted Scatterplot Smoothing method (LOWESS), also known as locally weighted regression [51], was used to investigate the two-dimensional variable relationships between explanatory variables and other factors, such as urban economic development and population size. Locally weighted regression is a classic nonparametric learning algorithm in which the model recalculates the regression coefficients for each prediction to achieve improved prediction results [52]. Different from the application of LISA, which focuses on identifying spatial autocorrelation, the use of LOWESS here is intended for exploring nonlinear bivariate associations between the variables.

The determination of weights in a local-weighted regression typically relies on the function of the distance between the observation and prediction points. Common methods include the Gaussian kernel function, the inverse distance method, and the bi-square function method. We employed a Gaussian kernel function as the weight coefficient determination method, as illustrated in Equation (4).

$$W_i = \exp\left(\frac{d_i^2}{-2k^2}\right) \quad (4)$$

where d_i denotes the distance between the point to be predicted and the nearby monitoring point, while k represents the wavelength, which determines the weight assigned to the nearby point. The smaller the k value, the larger the weight coefficient of the nearby point; conversely, the smaller the weight coefficient. Consequently, an excessively large k value results in overfitting, which weakens the generalization ability of the model. However, an excessively small k value will cause underfitting, strengthening the generalization ability of the model and increasing bias. Therefore, an appropriate wavelength directly affects the final prediction of the model. Generally, the optimal wavelength value of a model is obtained through cross-validation estimation. The Generalized Cross-Validation (GCV) criterion [53], a modified cross-validation method, was employed to compare the results and calculated using Equation (5):

$$GCV = \frac{1}{n} \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\left(1 - \frac{v_i}{n}\right)^2} \quad (5)$$

The sample size is represented by n , the observed value by y_i , the value predicted by $\hat{y}_i$, and the trace of the hat matrix by v_i . The local-weighted regression computation procedure mentioned above was executed in the R programming environment. The methodological procedure described above is shown in Figure 3.

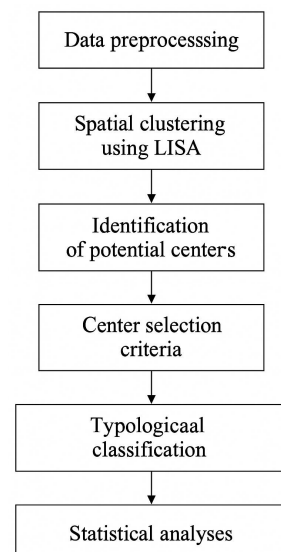


Figure 3. Methodological flowchart.

The differences in firm distribution across industries and regions may introduce bias in identifying urban centers. To mitigate this issue, our method relies on firm density rather than absolute firm count and applies a uniform 1 km × 1 km grid across all cities. This approach helps control for variations in city size and industrial structure. In addition, we adopted a consistent identification threshold across the 35 cities to enhance comparability and reduce the impact of data heterogeneity on the analysis results.

3. Results

3.1. The Number of Centers, Centralization Degree, and Primacy Ratio

The measurement results revealed a significant disparity in the number of urban centers in the 35 cities across different regions (Table 3, Figures 4 and 5). Among the 35 cities analyzed, the number of centers per city ranges from 1 to 23, with an average of 4.4 (Figure 5). Seven cities possess only one primary center and lack subcenters; 80% of the cities have at least one subcenter. Furthermore, 57% of the cities boast two or more subcenters, and 23% have five or more subcenters. Chongqing holds the record for the highest number of centers, reaching 23, a finding that aligns with the existing literature [30]. Overall, a polycentric spatial structure has emerged as a common phenomenon in large Chinese cities [14,29,31].

Table 3. Number of Centers, Centralization Degree, and Primacy Ratio measurements for the 35 cities.

City	Number of Centers	Centralization Degree	Primacy Ratio	Region
Shanghai	8	0.21	0.38	Eastern
Hefei	2	0.29	0.94	Central
Shenzhen	6	0.38	0.53	Eastern
Changsha	2	0.38	0.97	Central
Ningbo	2	0.39	0.87	Eastern
Fuzhou	2	0.43	0.93	Eastern
Taiyuan	2	0.46	0.66	Central
Guiyang	3	0.49	0.73	Western
Tianjin	11	0.50	0.49	Eastern
Xiamen	2	0.52	0.77	Eastern
Nanjing	5	0.55	0.55	Eastern
Guangzhou	11	0.58	0.77	Eastern
Wuhan	7	0.58	0.73	Central
Hangzhou	6	0.58	0.73	Eastern
Chengdu	4	0.58	0.86	Western
Beijing	11	0.60	0.75	Eastern
Shijiazhuang	1	0.61	1.00	Eastern
Zhengzhou	1	0.62	1.00	Central
Dalian	4	0.62	0.82	Northeastern
Shenyang	2	0.63	0.93	Northeastern
Jinan	5	0.65	0.74	Eastern
Xi'an	4	0.69	0.90	Western
Hohhot	1	0.70	1.00	Western
Kunming	3	0.70	0.92	Western
Lanzhou	3	0.73	0.70	Western
Xining	1	0.74	1.00	Western
Nanchang	1	0.78	1.00	Central
Chongqing	23	0.80	0.42	Western
Harbin	5	0.81	0.76	Northeast
Nanning	4	0.82	0.79	Western
Yinchuan	1	0.84	1.00	Western
Haikou	1	0.84	1.00	Eastern
Urumqi	2	0.85	0.83	Western
Changchun	3	0.88	0.88	Northeast

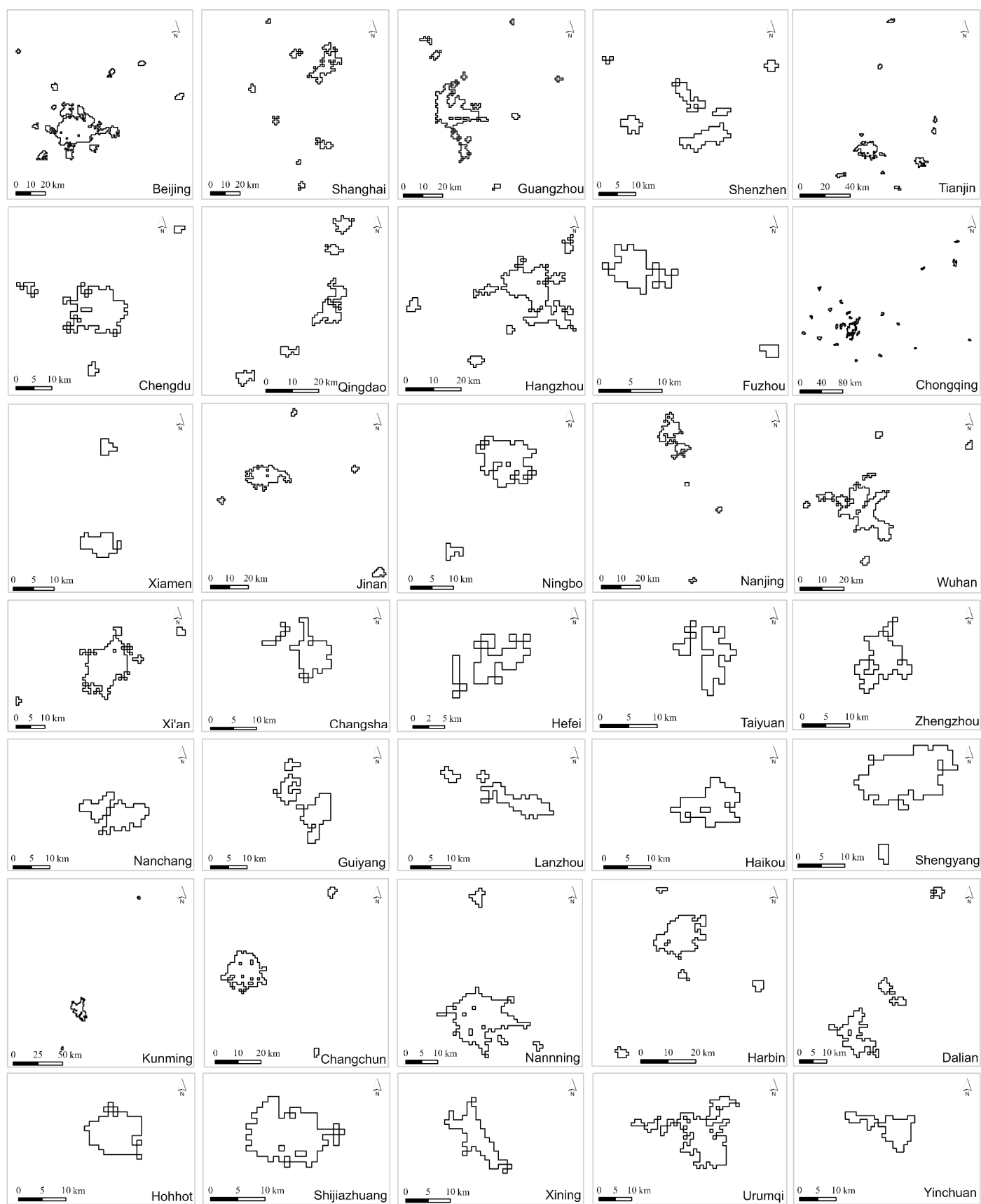


Figure 4. Location of urban centers in the 35 cities.

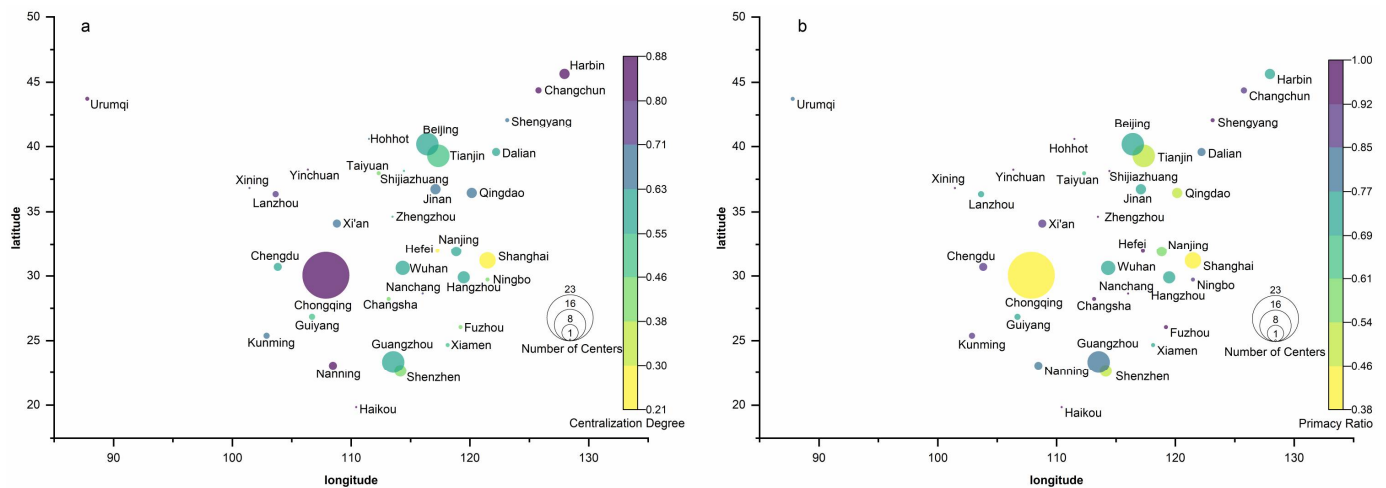


Figure 5. Number of centers and (a) centralization degree; (b) primacy ratio of the 35 cities.

The differences in centralization degree among the 35 cities are significant, with values ranging from 0.21 to 0.88 and an average of 0.62. Figure 5a illustrates the spatial distribution of urban centers and their centralization degree. Cities along the east coast with more developed economies, such as Shanghai, Shenzhen, and Ningbo, exhibit lower degrees of centralization. Among these cities, Shanghai has the lowest centralization degree, 0.21, indicating that only a fifth of firms are located in its various centers. The primary distribution of firms is not within the urban centers but is dispersed throughout non-central areas. In contrast, cities with relatively lagging economic development in the western and northeastern regions, such as Chongqing, Yinchuan, and Changchun, have higher degrees of centralization. Compared to the western and northern regions, cities in the central region (e.g., Hefei, Changsha) also have relatively lower levels of centralization.

The primacy ratios of the 35 cities exhibited significant differences (Figure 5b), with values ranging from 0.38 to 1 (i.e., monocentric cities) and an average of 0.80. Cities in the eastern and central regions have lower primacy ratios than those in the western regions [30,54]. Cities in the eastern region, such as Shanghai, Qingdao, Tianjin, and Shenzhen, had relatively lower primacy ratios. Among these, Shanghai's primacy ratio is the lowest of the 35 cities, indicating that it has the smallest proportion of firms located in multiple centers. In contrast, cities in the western region generally have a higher primacy ratio, signifying that their primary centers are crucial in the city's internal spatial structure.

3.2. The Typology of Polycentric Urban Spatial Structure

Based on the existing literature on concentration and dispersion process in the cities, it is contended that there exist different types of urban polycentricity: emerging polycentricity; centralized polycentricity; and dispersed polycentricity. As illustrated in Figure 6, theoretically, the dynamics of concentration and dispersion foster the emergence of urban centers [12]. In the monocentric structure (Figure 6a), urban elements (e.g., firms) are concentrated into the primary urban center. As the polycentric structure emerges (Figure 6b), the excessive agglomeration of urban elements in the primary center results in negative externalities, prompting urban elements to expand into areas beyond the urban center [55–58].

In the centralized polycentric structure (Figure 6c), the initial centrifugal diffusion process diminishes the center's agglomeration economies. However, as firms re-agglomerate in non-central areas, forming urban subcenters, they attract more businesses to congregate, subsequently raising each subcenter's agglomeration economies. With the continued development of subcenters, the phenomenon of agglomeration diseconomies re-emerges, causing firms to disperse from the subcenters to non-central urban areas.

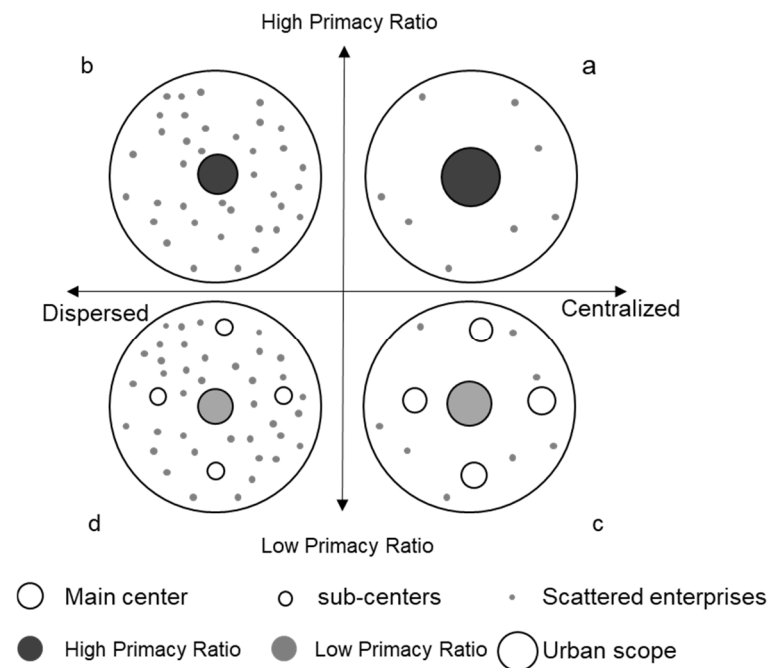


Figure 6. A typology of the urban polycentric system. (a) Monocentric structure; (b) Emerging polycentricity; (c) Centralized polycentricity; (d) Dispersed polycentricity.

The city then finally transforms into a dispersed polycentric structure (Figure 6d). It is admitted that this is a hypothesized model of urban spatial restructuring. Not all cities, and probably only a few very large cities, have transformed or will transform as the model predicts because of the constraints of their sizes, geographic boundaries, geological conditions, etc.

To better examine and understand the typology of the urban polycentricity, this study established the first and third quartiles of the number of centers, centralization degree, and the primacy ratio for comparison [8]. Figure 7a, the top right quadrant, represents cities in the monocentric structure, characterized by a high degree of centralization and a high primacy ratio. These cities had center numbers below the 25th percentile and a centralization degree and primacy ratio above the 75th percentile range, represented by Haikou, Nanchang, Yinchuan, and Xining.

The top left quadrant (Figure 7b) represents cities in emerging polycentricity, characterized by a low degree of centralization and a high primacy ratio. These cities have center numbers and centralization degrees below the 25th percentile and a primacy ratio above the 75th percentile, with Changsha and Hefei being the most typical examples.

The fourth (bottom right) quadrant of Figure 7c represents cities with centralized polycentricity, characterized by a high degree of centralization and a low primacy ratio. These cities have numbers of centers and degrees of centralization above the 75th percentile, and primacy ratios below the 25th percentile, with Chongqing being a typical representative.

The third quadrant of Figure 7d represents cities with dispersed polycentricity, characterized by a low centralization degree and a low primacy ratio. These cities—Shanghai, Shenzhen, Tianjin, and three others—have centralization degrees and primacy ratios below the 25th percentile and center numbers above the 75th percentile. Cities with dispersed polycentricity exhibit spatial morphological features of coexisting multi-centralization and decentralization, such as “widespread dispersion accompanied by multiple small-scale centers” [24,59,60].

To assess the robustness of the research findings, we increased the firm number threshold for defining an urban center from 10,000 to 15,000. The analysis results demonstrate that,

after increasing the central definition threshold, there was no significant difference in the number of centers, centralization degree or primacy ratio, suggesting stable measurement and analysis outcomes (see Appendix A for detailed results).

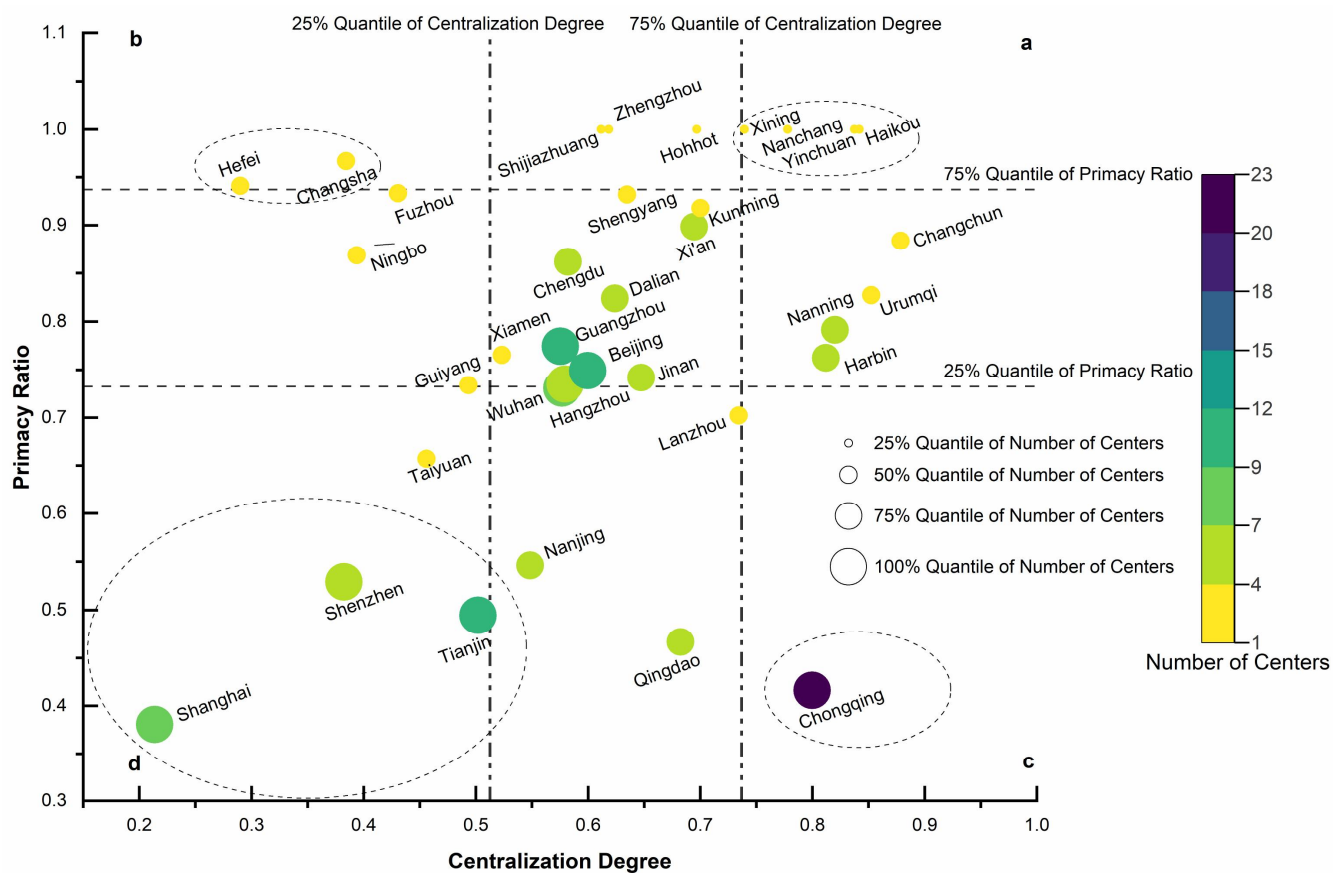


Figure 7. Number of urban centers, centralization degree, and primacy ratio of 35 cities. (a) High centralization degree and high primacy ratio; (b) Low centralization degree and high primacy ratio; (c) High centralization degree and low primacy ratio; (d) Low centralization degree and low primacy ratio.

3.3. The Factors Associated with the Urban Polycentricity Typology

The typology of urban polycentricity is shaped by a multitude of factors. In this study, we drew upon the existing literature to preliminarily explore the influence of socioeconomic development on polycentric structures using a locally weighted regression [13,29,30]. We chose the total population to represent the urban scale and GDP to represent the cities' economic development. Through a bivariate analysis, we explored the relationships between these two factors and our three indicators—number of centers, degree of centralization, and primacy ratio—and Table 4 presents a descriptive analysis of the variables.

The number of urban centers demonstrated a general positive association with an increase in population and GDP (Figure 8a). This observation aligns with the current research, which suggests that higher levels of urban economic development lead to a clearer polycentric urban structure [13]. Concurrently, based on the representative types of typical urban spatial structures discussed earlier, it can be inferred that the growth in the number of urban centers is relatively slow during the transition from a monocentric city to an emerging polycentric city. However, there was a sharp increase in the number of centers during the transition from emerging polycentricity to centralized polycentricity. Larger cities possess more urban centers, suggesting that the urban scale encourages the formation of polycentricity (Figure 8b). This observation aligns with the current phenomenon of

an increasing number of urban centers emerging in megacities such as Beijing, Shanghai, and Guangzhou.

Table 4. Descriptive Statistics of the Variables.

Variable Category	Variable Name	Variable Description	Obs	Mean	Std. Dev.	Min	Max
Dependent Variable	Number of centers	Number of identified urban centers	35	4.400	4.333	1.000	23.000
	Centralization Degree	The proportion of the number of firms in the polycentric urban areas to the total number of firms in the city, with a value range of 0 to 1.	35	0.615	0.167	0.214	0.879
	Primacy Ratio	The proportion of the number of firms in the primary center to the number of firms in all centers, with a value range of 0 to 1.	35	0.795	0.182	0.381	1.000
Social Factors	Total population	Total population of municipal districts (ln)	35	6.093	0.722	4.615	7.816
Economic Factors	GDP	Gross Regional Product (ln)	35	18.013	0.901	16.143	19.760

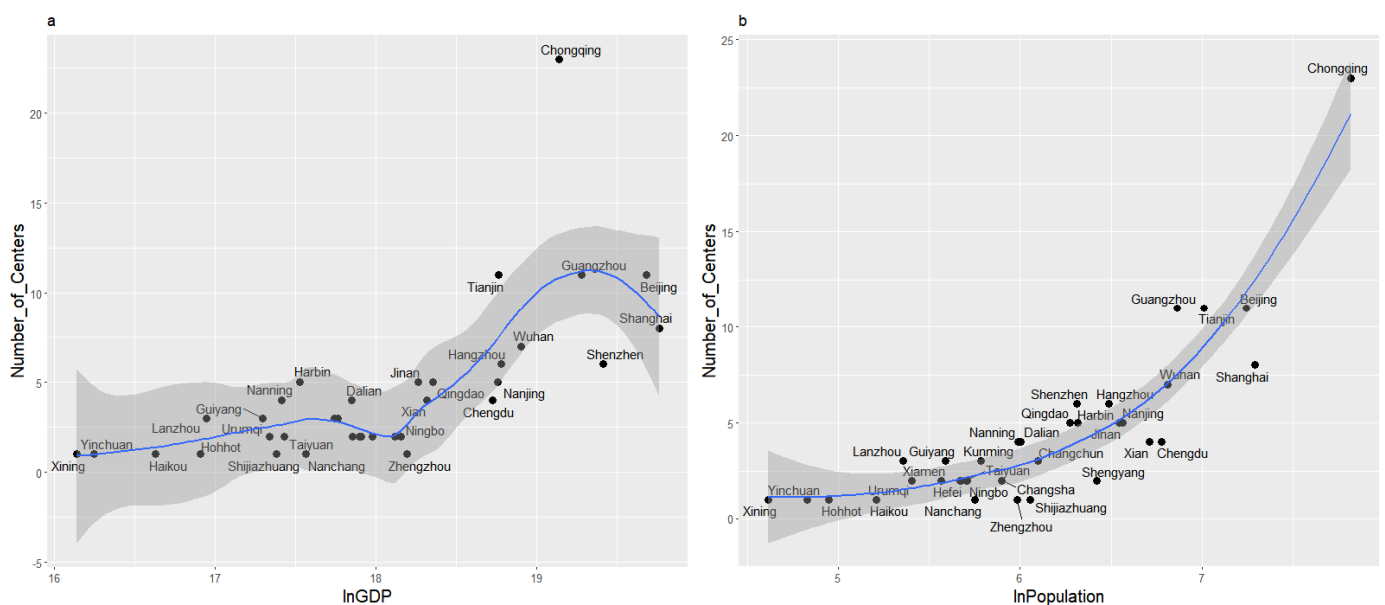


Figure 8. LOWESS regression results of the number of urban centers with GDP and population in the 35 Chinese cities. (a) Relationship between the number of urban centers and GDP; (b) Relationship between the number of urban centers and population.

The relationships between the degree of centralization and both urban economic development and population scale exhibited a much more complicated pattern (Figure 9). Cities with monocentric structure exhibit the highest centralization degree, as most firms are concentrated in the primary and only urban center. With economic development and population increases, agglomeration diseconomies arise, prompting firms in the primary center to disperse outwards, thereby reducing the degree of centralization of the urban center and reaching a low point during the mature monocentric stage. As the city continues to

develop, firms within the city re-concentrate, and the monocentric urban state transitions to an emerging polycentric stage, increasing the degree of urban centralization. Subsequently, agglomeration diseconomies reoccur, and excessively high rents and costs compel firms within the city to expand to non-central areas, causing the city to transition to dispersed polycentric stage and the degree of urban centralization to decrease [58,61,62].

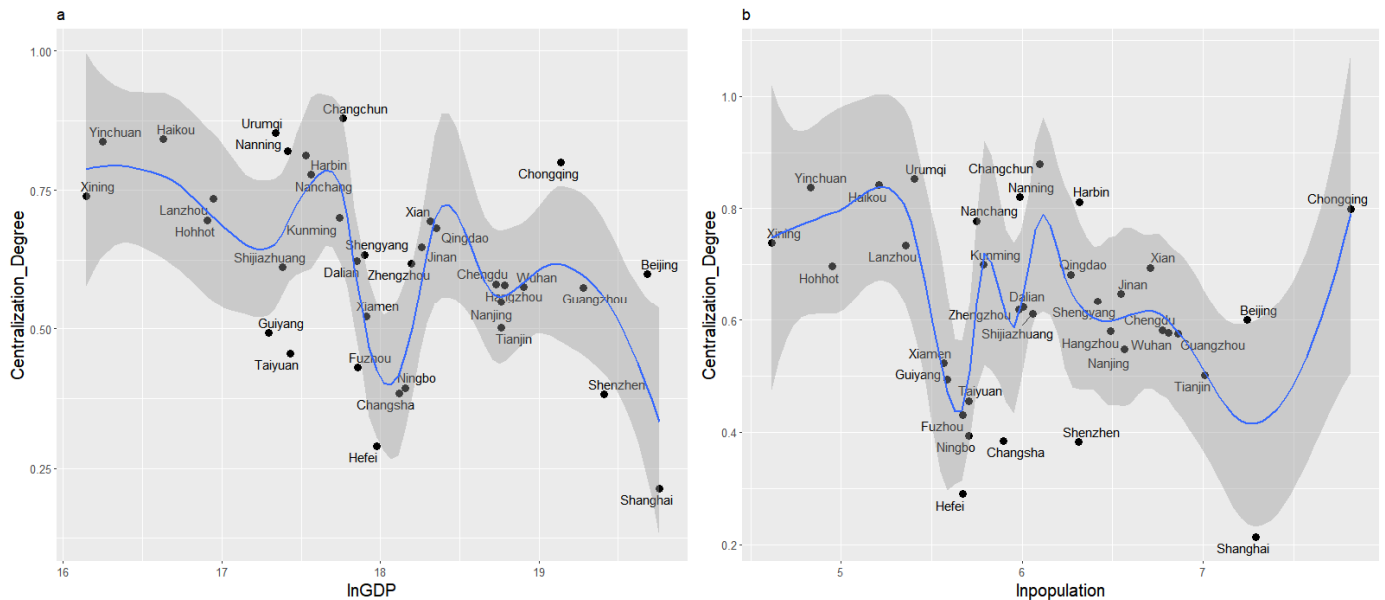


Figure 9. LOWESS regression results of centralization degree with GDP and population in the 35 Chinese cities. (a) Relationship between centralization and GDP; (b) Relationship between centralization and population.

The associations between primacy ratio, population size, and GDP exhibited a decreasing trend overall, with a small increase in the middle (Figure 10). The general decreasing trend might be because, as urban economic development and population size continue to grow, they promote the flow of population and industries out of the main CBD, consequently reducing the primacy of the primary center. This allows firms and populations to be more evenly distributed among various urban centers rather than being excessively concentrated in the primary center. It is worth noting that during the transition from monocentricity to emerging polycentricity, the primacy ratio experienced a slight increase, as the role of the primary center was the strongest during this period. Subsequently, it appears to decline with the development of the urban economy and population. This means that after the transition from monocentricity to polycentricity, the primacy ratio or role of the primary center continues to weaken [8,13,16].

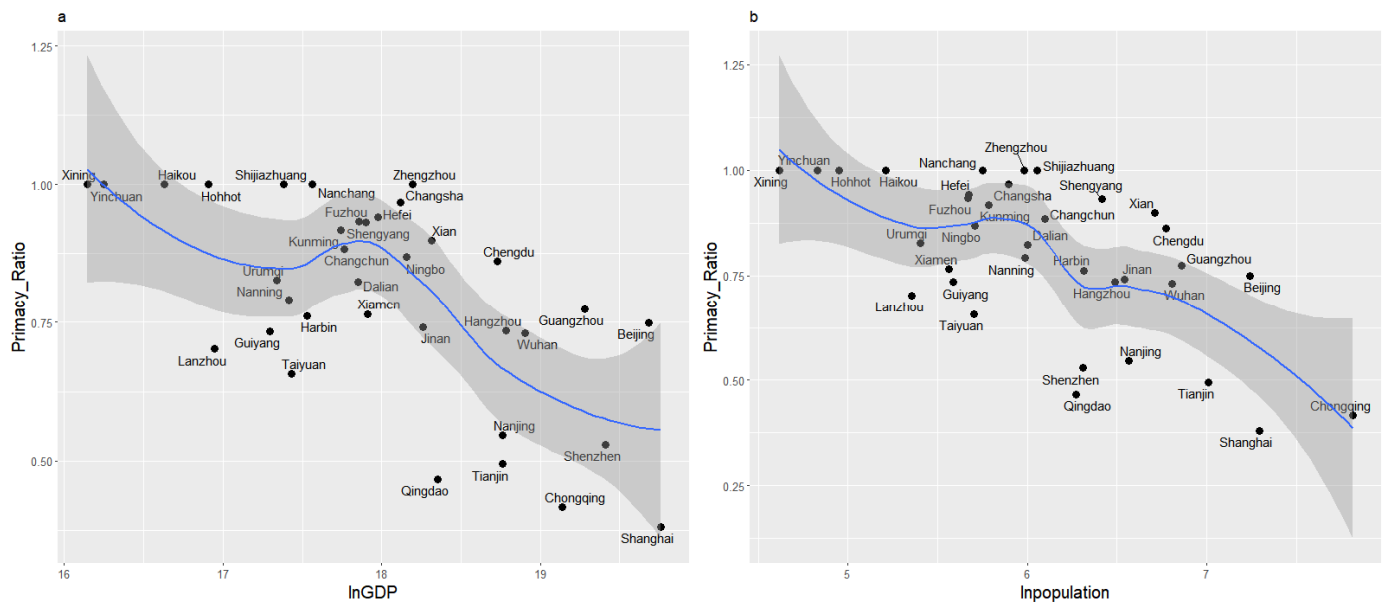


Figure 10. LOWESS regression results of the urban center's primacy ratio with GDP and population in the 35 Chinese cities. (a) Relationship between primacy ratio and GDP; (b) Relationship between primacy ratio and population.

4. Discussion

In examining urban internal spatial structures, this study goes beyond the basic dichotomy of “monocentric” and “polycentric”. Employing the number of urban centers, degree of centralization, and primacy ratio as analytical tools, this study conducted a comparative analysis of urban internal spatial structures in the distribution of firms across 35 major Chinese cities. The findings can be summarized as follows.

First, our results demonstrate that the internal spatial structure of large Chinese cities exhibits a pronounced trend toward polycentricity. However, there are considerable variations in the polycentric structures of cities across regions and developmental stages. Cities in the eastern and central regions possess more centers, and their primacy ratios are comparatively lower than those in other regions. Among the 35 large cities, Shanghai has the lowest degree of centralization and primacy ratio.

Second, our study demonstrates that the polycentric structures of large cities demonstrate three different patterns. This is evident from the fluctuations in the number of centers, centralization degree, and primacy ratio. For the cities with an emerging polycentric structure, the degree of centralization declines, whereas the primacy ratio remains elevated. For the cities with a centralized polycentric structure, the number of centers increases, the degree of centralization increases, and the primacy ratio diminishes. For the cities displaying a dispersed polycentric structure, both the centralization degree and primacy ratio are lower than in the previous category.

Third, our study demonstrates that, in general, the typology of polycentric urban spatial structures is associated with the socioeconomic development of cities. The number of urban centers tends to increase in correlation with the level of economic development and urban population size. The centralization degree demonstrates a complicated “W” relationship with economic development and population size. In general, the primacy ratio decreases with an increase in population size and GDP.

The proposed typology may offer meaningful insights for guiding urban planning and policy formulation in the context of evolving spatial structures. For cities exhibiting an emerging polycentric structure, targeted infrastructure investments may help reinforce the spatial connection of newly forming subcenters and prevent uncontrolled sprawl. Cities

characterized by a centralized polycentric structure may benefit from transit-oriented development and improved connectivity between the primary center and surrounding areas to enhance spatial efficiency. In contrast, cities with a dispersed polycentric structure might face coordination and governance challenges, requiring more integrated and regionally coordinated planning approaches. Understanding these distinct spatial configurations could help planners tailor zoning policies and infrastructure strategies to better match local urban dynamics.

Beyond the practical implications, the proposed typology also contributes to urban spatial theory by offering a systematic framework for interpreting intra-urban structural diversity. By integrating multiple indicators (number of centers, centralization degree, and primacy ratio), the typology facilitates nuanced differentiation between patterns that go beyond the conventional monocentric–polycentric binary. This framework can serve as a foundation for future empirical investigations that seek to link polycentric structures with urban performance metrics such as mobility, livability, and spatial equity. Additionally, it offers a comparative basis for examining how institutional, cultural, or developmental contexts shape spatial outcomes in different cities.

It is also worth noting that while this study focuses on Chinese cities, the findings may have broader implications. Our typological framework and analytical approach are grounded in the established literature on urban spatial structure, much of which originates from studies in the West. This conceptual lineage enhances the comparability and generalizability of our study. Meanwhile, we acknowledge the institutional particularities of Chinese cities, such as their transitional economic systems and state-led urban development, which may limit the direct applicability of our conclusions. Nonetheless, with appropriate adaptation, the findings from this study could inform comparative research and planning practices in other rapidly urbanizing regions.

5. Conclusions

Drawing on the proposed theoretical typology and detailed empirical findings, this study moves beyond the basic comparisons of monocentric versus polycentric cities in the extant literature. By utilizing firm spatial distribution data to examine the polycentric structure of Chinese cities, it offers a fresh perspective for research on urban internal spatial organization and a novel approach for investigating the factors influencing various indicators of polycentric structure. By displaying the characteristics of the emerging, centralized, and dispersed polycentric structures, the study enhances the understanding of urban scholars concerning the different urban spatial structures that exist in reality. This should provide evidence-based policy recommendation for planners who contemplate the direction of future urban spatial transformations.

The limitations of this study and possible ideas for future work are as follows. First, this study only examines the spatial distribution of firms within the urban districts of the 35 cities, which does not strictly correspond to urban areas. Although municipal districts typically cover a broader area than the urban core, which could lead to an overestimation of urban spatial extent, we mitigate this limitation in two ways. On the one hand, our center identification method emphasizes spatial continuity, ensuring that only contiguous and densely clustered firm areas are recognized as urban centers. On the other hand, we adopt a stringent identification threshold (10,000 firms and at least three adjacent high-density grids), which helps filter out weak signals and reduce the risk of overgeneralization.

Nevertheless, in smaller cities with relatively few businesses, the limited number of firms may still constrain the robustness of center identification and typological classification, even under conservative criteria. Future research could improve the precision of analysis, particularly in such contexts, by incorporating complementary indicators such as

employment density, land-use intensity, or commuting patterns. It will also be essential to further investigate each city's specific spatial characteristics and examine the internal structure of built-up or functional urban areas.

Second, this study only explored the potential association between urban spatial structure and some socioeconomic factors. In the future, when data availability improves, longitudinal research should be conducted to validate the accuracy of the current research findings and to examine causal relationships. As mentioned earlier, it would be also better to analyze employment data rather than firm data.

Third, this study offers an initial exploration of the scale and hierarchical structure of the urban center system. However, it does not account for the functional dimensions of polycentricity, such as industrial clustering and economic specialization. Integrating such functional indicators would help construct a more comprehensive understanding of urban polycentric structures, including the characteristics and underlying mechanisms of functional differentiation among centers.

Moreover, this study primarily focused on GDP and population as key socioeconomic indicators to establish a baseline typology. Future research could expand the analytical framework to incorporate other critical factors such as transportation infrastructure, land-use planning, and real estate dynamics to further enrich the understanding of polycentric urban structures.

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Appendix A

To assess the robustness of the research findings and enhance the urban center screening criteria [30], the firm number threshold for defining an urban center was increased from 10,000 to 15,000. The analysis results are presented in Table 3, revealing a minor discrepancy in center identification outcomes between the two threshold levels. In total, 66% of the new urban center identification results aligned with those generated using the 10,000-firm threshold. Chongqing remains the city with the highest number of centers, while the number of cities with no subcenters has increased by two (Hefei and Changsha). The number of centers in the 12 cities has fallen, with Guangzhou losing three subcenters; Shanghai, Chongqing, Tianjin, and Wuhan losing two subcenters; and the remaining cities losing one subcenter each.

Table A1. Number of centers, centralization degree, and primacy ratio measurements for 35 cities under the 15,000-firm threshold.

City	Number of Centers	Centralization Degree	Primacy Ratio	Change in Centers Compared with 10,000-Firm Threshold
Shanghai	6	0.205	0.396	−2
Hefei	1	0.273	1	−1
Shenzhen	5	0.379	0.533	−1
Changsha	1	0.372	1	−1
Ningbo	2	0.394	0.869	Unchanged
Fuzhou	2	0.431	0.933	Unchanged
Taiyuan	2	0.456	0.657	Unchanged
Guiyang	3	0.493	0.734	Unchanged
Tianjin	9	0.482	0.515	−2
Xiamen	2	0.523	0.765	Unchanged
Nanjing	4	0.538	0.557	−1
Guangzhou	8	0.561	0.794	−3
Wuhan	5	0.562	0.749	−2
Hangzhou	5	0.568	0.749	−1
Chengdu	4	0.582	0.862	Unchanged
Beijing	10	0.595	0.755	−1
Shijiazhuang	1	0.612	1	Unchanged
Zhengzhou	1	0.618	1	Unchanged
Dalian	3	0.610	0.843	−1
Shenyang	2	0.635	0.932	Unchanged
Jinan	5	0.647	0.742	Unchanged
Qingdao	5	0.682	0.467	Unchanged
Xi'an	4	0.695	0.898	Unchanged
Hohhot	1	0.697	1	Unchanged
Kunming	3	0.700	0.918	Unchanged
Lanzhou	3	0.734	0.702	Unchanged
Xining	1	0.739	1	Unchanged
Nanchang	1	0.778	1	Unchanged
Chongqing	21	0.785	0.424	−2
Harbin	5	0.812	0.762	Unchanged
Nanning	4	0.820	0.791	Unchanged
Yinchuan	1	0.837	1	Unchanged
Haikou	1	0.842	1	Unchanged
Urumqi	2	0.852	0.827	Unchanged
Changchun	3	0.879	0.884	Unchanged

A comparative analysis of Tables 2 and 3 demonstrates that after increasing the central definition threshold there was no significant difference in the calculated centralization degree or primacy ratio, resulting in relatively stable measurement outcomes. The centralization degree measurements indicate that with the 15,000-firm threshold, the numerical range remains constant, with an average of 0.61, deviating only slightly from the 0.62 average using the 10,000-firm threshold. The overall ranking by degree of centralization remains largely consistent, with Shanghai maintaining the lowest value. The sequence of the top nine and bottom 13 cities remained almost the same, with only two cities exchanging positions. The range of the primacy ratio shifts from 0.40–0.88 to 0.38–0.88, while the average remains unaltered. The overall ranking order was also predominantly consistent, with Shanghai having the lowest primacy ratio among all cities. The order of the top eight and bottom 15 cities persisted, with only a few cities switching places.

By again employing the 25th and 75th percentiles of the three indicators (center number, centralization degree, and primacy ratio) to assign the cities to urban spatial structure types (as outlined in Figure 1), we see a great similarity between the findings at the original 10,000-firm threshold and the new 15,000-firm threshold (Figure A1). These results substantiate the robustness of the findings of this study.

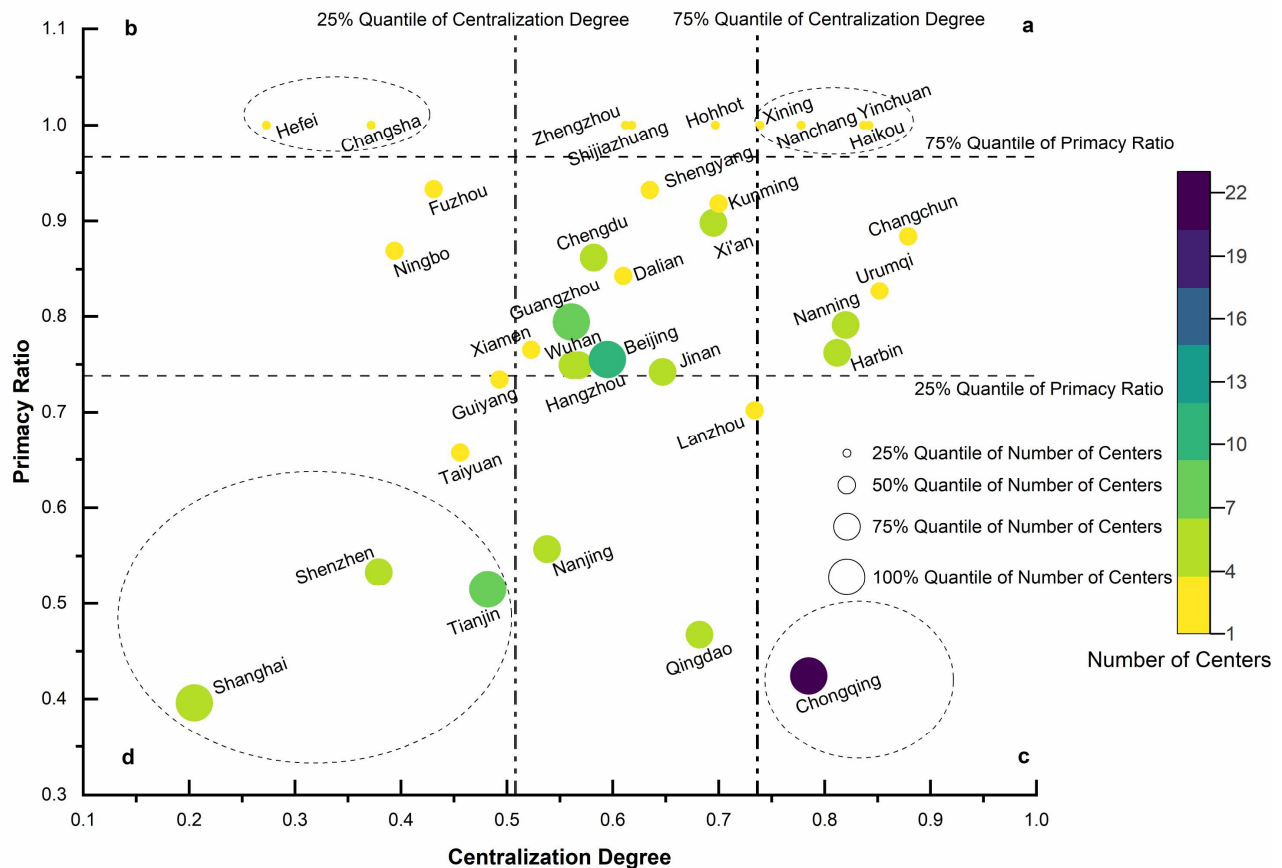


Figure A1. Number of urban centers, centralization degree, and primacy ratio of the 35 cities using the 15,000-firm threshold. (a) High centralization degree and high primacy ratio; (b) Low centralization degree and high primacy ratio; (c) High centralization degree and low primacy ratio; (d) Low centralization degree and low primacy ratio.

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