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The spatial-temporal evolution of urban development patterns in Chinese cities: Dynamics and interpretations

Wenzheng Li | **Stephan Schmidt**

Department of City and Regional Planning, Cornell University, Ithaca, New York, USA

Correspondence
Wenzheng Li, Department of City and Regional Planning, Cornell University, 129 Sibley Dome, Ithaca, NY 14853, USA.
Email: wl563@cornell.edu

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Abstract

This paper examines the spatial-temporal evolution of urban spatial structure across 269 Chinese prefectural cities from 2002 to 2019. Our analysis identifies a consistent trend toward a more polycentric configuration in the 25 Chinese mega-cities during this period, primarily due to population growth and a supportive policy environment. However, the evolutionary pathways of small- and medium-sized cities unfolded in a rather complex and diverse manner, with some becoming more polycentric while the majority adhering to a monocentric trajectory. In these cases, population growth is usually associated with a more monocentric pattern, characterized by rapid expansion of the urban core, while polycentric development is primarily attributed to specific spatial policies that support the emergence of subcenters. We conclude that polycentric development, while potentially suitable for mega-cities to alleviate diseconomies of scale, may be less appropriate for small- and medium-sized cities as it may constrain growth associated with agglomeration economies. We suggest that the development and implementation of regional spatial policy should be considerate of local historical paths and contextual factors. Finally, we propose a stylized framework to more accurately reflect the diverse and complex nature of urban spatial structure evolution in Chinese prefectural cities.

KEYWORDS
China, decentralization, polycentricity, regional planning, spatial planning, urban spatial structure

1 | INTRODUCTION

For over two decades, urban scholarly and policy discussions have engaged with the concept of metropolitan polycentricity, considering it a more accurate depiction of contemporary urban spatial structure compared to the traditional monocentric model. Polycentricity has been applied in various analytical and normative-political scenarios, as interpreted by scholars across various social, geographical, and cultural contexts (Davoudi, 2003; Kloosterman & Musterd, 2001; van Meeteren et al., 2016). Despite, or because of, its definitional ambiguity, a literature has emerged focused on not only the measurement and operationalization of polycentricity at different spatial scales but also the empirical analysis of the supposed benefits or outcomes of polycentric development (see, e.g., Burger & Meijers, 2012; Jin & Xu, 2024a; Li et al., 2023; Li & Schmidt, 2024; Sun et al., 2019; Wang et al., 2019). Nevertheless, despite this interest, the evolution of urban spatial structure and the emergence of polycentric urban configurations has received relatively little attention (Arribas-Bel & Sanz-Gracia, 2014; Bartosiewicz & Marcinczak, 2022; Hajrasouliha & Hamidi, 2017).

How do urban spatial patterns evolve over time? How do polycentric patterns emerge? Resolving these questions presents a challenge due to the diverse academic origins of the literature discussing them and the variability arising from different spatial scales and geographical contexts (van Meeteren et al., 2016). Studies in the US have typically focused on the intra-urban spatial structure of metropolitan areas, built upon the classic monocentric model, and are particularly interested in emerging suburban nodes and the ways in which they function (Anas et al., 1998; Cervero & Wu, 1997; Garreau, 1991; Giuliano et al., 2019, 2022; Gordon & Richardson, 1996; Lee, 2007). These studies assume that the development of a polycentric pattern is the result of the decentralization of economic activities, decreasing transport costs, economic restructuring, and evolving individual and household preferences (Carruthers & Mulligan, 2012; Clark & Murphy, 1996; Frey, 1993). Within the European context, studies of polycentricity are more focused on the inter-urban scale. Significant emphasis has been placed on the notion of polycentric urban regions (PUR), characterized by the presence of multiple proximate core cities with comparable size and multidirectional functional connections among them (Hall & Pain, 2006; Parr, 2004; Volgmann & Münter, 2022). The establishment of PURs may involve the incorporation or regional integration of multiple pre-existing independent and self-sufficient centers (Champion, 2001; Münter & Volgmann, 2021). Notably, both strands of this literature regard agglomeration economies as their theoretical underpinning. Beyond this, however, the evolutionary pathways of spatial structures vary and are influenced by demographic, economic, transportation, and political factors, as well as the initial configuration of the urban system (Burger et al., 2011; Duranton & Puga, 2014; Garcia-López et al., 2017).

Beyond the US and Europe, recent scholarly inquiries into the evolution of urban spatial structure have expanded to include Chinese cities and regions. As China has rapidly urbanized, the growth and evolution of urban spatial patterns have unfolded in ways that are familiar to a

Western observer. Population and firms, once centralized in urban cores, have decentralized and reconcentrated in the urban fringe in response to increasing congestion and skyrocketing housing prices (Hu et al., 2018, 2020). Meanwhile, substantial real estate investments in the suburbs, coupled with enhanced transport accessibility, have further accelerated this process (Baum-Snow et al., 2017; Dong et al., 2021; Meng et al., 2021). Additionally, natural features such as topography and water continue to influence spatial patterns (Liu et al., 2019; Liu & Wang, 2016). However, given China's unique characteristics and context, knowledge derived from Western countries may not universally apply to Chinese cities, as urban spatial structures are path-dependent and context-specific. One distinctive characteristic of many Chinese cities is that they are impacted and acted upon by explicitly spatial national and local development policies, as evidenced by the establishment of a variety of new districts and subcenters that serve as industrial parks, administrative centers, and innovation hubs, among others (Cheng & Shaw, 2018; Phelps et al., 2023). This includes the recent establishment of an administrative subcenter in Beijing, and special economic zones in Shanghai and Tianjin. Numerous smaller new districts and subcenters have also been established in small- and medium-sized cities by provincial and local governments (Feng, 2015).

Empirical analysis suggests that Chinese mega-cities, such as Beijing, Shanghai, Guangzhou, and Tianjin, are evolving into more polycentric configurations (Cheng & Shaw, 2021; Huang et al., 2017; Wang et al., 2020). A limited number of studies drawn from a larger sample of Chinese cities also conclude that Chinese cities have generally become more polycentric (Li, 2020), but for the most part, much of the research has been geographically selective, focusing on a couple of polycentric mega-cities. This narrow sampling preference may lead to a biased observation that the trend toward polycentricity is ubiquitous in China, whereas this may not be the case (Bartosiewicz & Marcinczak, 2022). For example, research by Li and Derudder (2022) on 286 Chinese cities uncovered both increases and decreases in the proportion of subcenter populations, suggesting diverse evolutionary paths in urban structures. Moreover, despite a growing awareness of this selection bias and efforts to inclusively incorporate a wider array of cities, the heterogeneous evolution of urban structures, particularly among cities of varying sizes, is still insufficiently understood. Consequently, we still lack a comprehensive and accurate depiction of evolutionary trajectories for a large set of cities characterized by differing sizes and diverse socioeconomic, political, and geographical contexts.

An analysis of the evolution of Chinese urban spatial patterns also has implications for spatial policy. Within a rapidly urbanizing context, we submit that polycentrism may not necessarily be a desirable goal for all cities, as its effectiveness relies on achieving a "critical mass" (Burgalassi, 2010; Davoudi, 2003; Wang et al., 2019). Large cities may be inherently better positioned to adopt polycentric development, as agglomeration diseconomies are more likely to outweigh agglomeration benefits. By contrast, promoting a polycentric configuration for smaller and medium-sized cities before they reach a critical mass might deprive them of the opportunity to foster industrial agglomeration, potentially yielding adverse impacts on economic growth. This issue merits particular attention in China, where discussions and plans for building new towns and subcenters are pervasive in spatial and regional planning documents. Consequently, evaluating the evolutionary pathways of urban structure contingent on city size becomes imperative, as strategies to encourage polycentricity may produce outcomes of varying efficacy, and in some cases, undesirable ones, based on each city's unique contexts and developmental stage.

This study aims to quantitatively associate heterogeneous evolutionary patterns of urban structure with Chinese prefectural cities of varying sizes and provide insights into the characteristics and determinants of changes in urban spatial structure. Specifically, we classified 269 prefectural cities into groups of large, medium, and small based on population size, and identified their evolutionary trajectories from 2002 to 2019. We further investigated the determinants of their spatial evolution during that time, considering demographic, economic, geographical barriers, and policy factors. By thoroughly examining the multifaceted scenarios of urban structure, we synthesized a stylized framework to offer a more comprehensive and precise depiction of the evolution of urban structure tailored to Chinese cities. To ensure methodological robustness and to facilitate comparison with similar studies, such as Li (2020) and Li and Derudder (2022), we chose the widely-used Landscan dataset and methods to operationalize polycentricity. Our approach drew upon the stepwise polycentricity (SP) method developed by Zhang and Derudder (2019), enabling the classification of cities into three categories based on their unique SP trajectories. This method is complemented with a continuous polycentricity (CP) index initially proposed by Green (2007) and modified by Liu and Wang (2016), aiming to capture nuanced variations in urban spatial structure for each city.

This paper is organized as follows. Section two outlines the study area, data, and methods used to operationalize polycentricity. Section three analyzes the spatial-temporal patterns of urban structural evolution for cities of varying sizes. In section four, we interpret the emergence or absence of polycentric and monocentric trends according to a set of influential factors. Section five proposes a stylized framework that provides a more precise depiction of urban structure evolution for Chinese cities, followed by a conclusion summarizing findings and limitations in the final section.

2 | DATA AND METHODS

2.1 | Research area and data

As Thomas et al. (2021) suggested, quantifying polycentricity involves a three-stage process: delineating regions, identifying centers, and operationalizing polycentricity. Each stage entails methodological choices that can yield diverse outcomes. We selected Chinese prefectural-level cities as the unit of regional delineation, in line with the choice adopted in previous works by Li and Derudder (2022) and Sun et al. (2019). A typical prefectural city[1] includes an urban core surrounded by a hinterland composed of multiple counties and county-level cities. We excluded cities lacking significant centers, as determined by our center identification algorithm. These excluded cities generally exhibit a decentralized urban structure and are mostly located in the sparsely populated western areas (Figure 1a). The final dataset comprises 269 prefectural cities.

The Landscan High-Resolution Global population dataset (Figure 1b), developed by the Oak Ridge National Laboratory, serves as the primary data source to identify centers and quantify polycentricity. This dataset integrates multiple spatial and census data sources to comprehensively represent ambient (24-h average) population distribution at a 1 km-by–1 km grid level (Mesev, 2003). The product is updated annually, and the estimation model has been consistently improved by incorporating advances in geospatial and machine learning algorithms. While social media data (e.g., cell phone location) and nighttime light imageries may serve as alternatives, the former is typically acquired at a single time point, making it unsuitable for

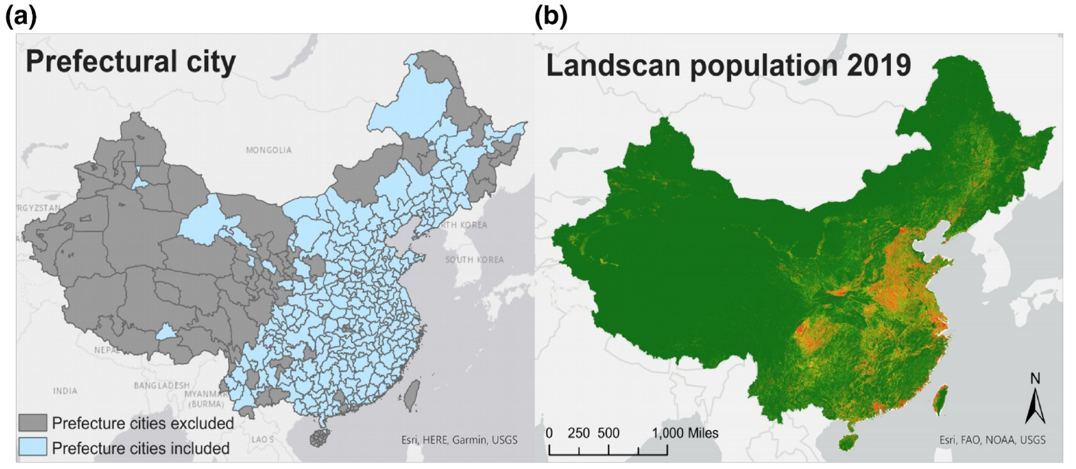


FIGURE 1 (a) Boundaries of the 269 Chinese prefectural cities analyzed in this study; (b) Landscan global population distribution in China.

longitudinal analysis. The latter is susceptible to technical issues like pixel saturation and inconsistent satellite censors (Li et al., 2020). To eliminate the impact of the pandemic on urban spatial structure, we chose two pre-COVID-19 time points, 2002 and 2019, for comparison, and utilized several intermediate time points (i.e., 2007, 2012, and 2017) as a robustness check for the consistency of the Landscan dataset. We are aware that the resolution of the Landscan data may limit its ability to capture very detailed urban structures of smaller cities, particularly undergoing rapid change; however, due to its widespread use and comprehensive extent of monitoring urban expansion and spatial patterns under the Chinese context (see, e.g., Jin & Xu, 2024b; Li, 2020; Li & Derudder, 2022), we feel it is still an accurate representation of urban change.

2.2 | Identifying centers

Quantifying polycentricity requires the identification of urban centers within each city. Although consensus on the approaches for identifying these centers is lacking, scholars generally agree that a center should be characterized as a contiguous area exhibiting markedly higher employment or population density, and of a size large enough to influence the city's overall urban structure (Giuliano & Small, 1991). In this study, we employ a combined methodology that incorporates local spatial autocorrelation (LISA) and geographic weighted regression (GWR), building upon the work by Cai et al. (2017). First, LISA identifies the main center as the largest cluster exhibiting local high-high or high-low cluster values. Subsequently, a (non)parametric regression approach is employed to identify subcenters. This process involves using the weighted mean centroid of the main center as the city center (CBD) and using the GWR to regress the square root of population density against the distance from each grid cell to the CBD. Local peaks along the population density gradient, which are statistically significant (t value > 1.96), are selected as candidate subcenters. For GWR parameter specification, we employ the Gaussian function to determine the adaptive distance and cross-validation (CV) to specify the bandwidth for the spatial weight matrix.

2.3 | Operationalizing polycentricity

This paper utilizes two methods to quantify polycentricity from a morphological perspective: the CP index developed by Green (2007) and the SP typology introduced by Zhang and Derudder (2019). Both methods are based on the premise that a more evenly distributed population or employment across urban centers reflects a higher degree of polycentricity. The SP typology is specifically designed to assess how the measure of polycentricity is affected by the inclusion of varying numbers of urban centers. The first step to implementing the SP typology approach involves calculating a set of polycentric indices following the method outlined by Green (2007). For each top n centers (n = 2,3,...,m):

$$P_i(n) = 1 - \sigma_n/\sigma_{\max}$$

where $P_i(n)$ is the degree of polycentricity for city i considering the top n centers; σ_n represents the standard deviation of the population for the top n centers; and $\sigma_{\max}$ denotes the maximum standard deviation considering an absolute monocentric two-center scenario.

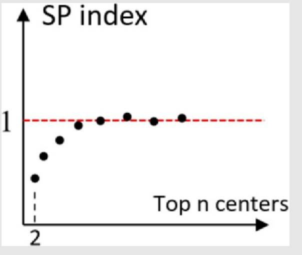
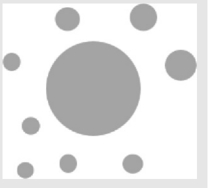
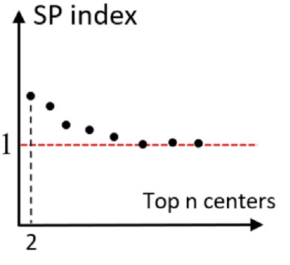
In the next step, each $P_i(n)$ is benchmarked against the degree of polycentricity of a hypothetical city population distribution following the Zipf's Law[2]:

$$SP_i(n) = P_i(n)/P_{Zipf}(n)$$

For each region, we obtain a set of SP indices, $SP_i(2)$,$SP_i(3)$, ...,$SP_i(m)$, each representing the degree of polycentricity by a certain number of centers incorporated. Next, we visualize SP trajectory for each city, representing the number of incorporated centers on the x-axis and the corresponding SP indices on the y-axis. This yields a distinct SP trajectory for each city, categorized into one of the three typologies: monocentric, multicentric, and polycentric cities. Table 1 summarizes the definition, SP trajectory, and stylized diagram of urban spatial structure for each group. The monocentric group (G1) denotes a city with only one center. The multicentric group (G2) indicates that a city has at least two centers, with a size distribution less balanced than the benchmark city following Zipf's Law. The polycentric group (G3) suggests the presence of a minimum of two centers, and their size distribution either adheres to Zipf's law or exhibits a more balanced distribution.

In addition to the SP typology, we employ the CP index as an alternative measure of polycentricity, recognizing that the SP typology may not adequately capture nuances in urban spatial patterns, particularly micro-scale migration and land development. The process of generating the CP index aligns with the first two steps of constructing the SP typology. One limitation of the CP index is that it varies based on the number of incorporated centers (Zhang & Derudder, 2019). To mitigate this bias, we report the CP index calculated using the top two (largest) centers per city, ensuring the comparability of the degrees of polycentricity across cities with different numbers of centers. Additionally, we calculate the CP indices using the top three and four centers as robustness checks. The results show that incorporating the different numbers of centers (i.e., two, three, and four) has negligible influence on our conclusion. Further details on generating the CP index and the robustness check are available in the Supporting Information S1.

TABLE 1 The definition, trajectory, and stylized diagram of the stepwise polycentricity (SP) typology modified from Zhang and Derudder (2019).

Group name	Definition	Trajectory of stepwise polycentricity	Diagram of urban structure
Group 1: Monocentricity	• Single-centered region—only one center identified	N/A	
Group 2: Multicentricity	• A region with two or more centers and the size distribution of centers is less balanced than that of a benchmark region following Zipf's Law. • The SP index calculated by multiple or, at least, the top two centers is less than 1.		
Group 3: Polycentricity	• A region with at least two centers and the size distribution of centers follows Zipf's Law or demonstrates a more balanced distribution than a benchmark city following Zipf's Law. • The SP index calculated by multiple or, at least, the top two centers is equal to or greater than 1.		

2.4 | The interpretation of SP trajectories

We selected three representative prefectural cities—Shenzhen, Tianjin, and Wuhan—to demonstrate the application of the SP method and clarify the process of categorizing cities into their respective groups. Figure 2 presents the SP trajectories for each city in both 2002 and 2019 and the identification of city centers. Shenzhen, recognized as one of the largest and fastest-growing cities, experienced a transition from a multicentric (G2) to a polycentric (G3) urban pattern. This transition is evidenced by the trajectory transformation from a convex curve in 2002 to a concave curve in 2019, particularly when focusing on the city's leading centers. A driving factor for this transformation is the development of the Baoan district in the northwestern part of Shenzhen. Notably, we classify a city as polycentric (G3) as long as the SP index incorporating the top two centers equals or exceeds 1. This criterion aligns with the consensus in previous studies, which suggests that the spatial structure of a city or region is predominantly shaped by a handful of major centers (Meijers & Burger, 2010; Zhang & Derudder, 2019).

In contrast to Shenzhen's evolving urban structure, Tianjin, a major northern Chinese city, displayed a consistent multicentric pattern (G2→G2) throughout the study period. This is demonstrated by the initial SP indices in both 2002 and 2019 trajectories, which remained below

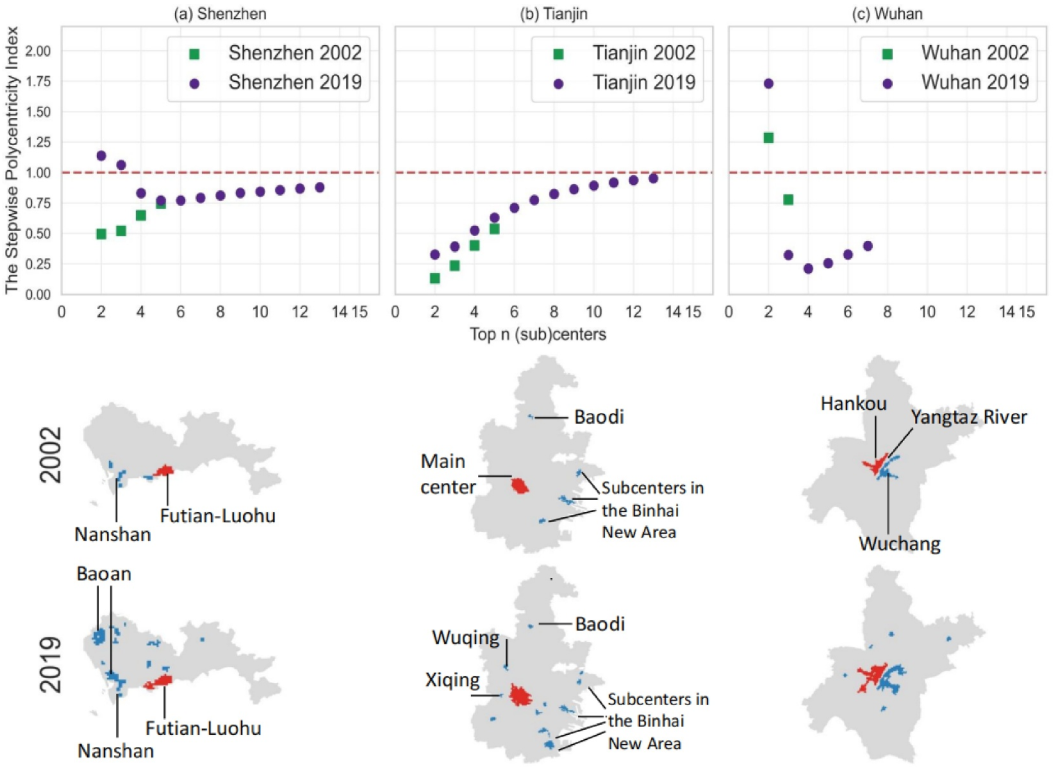


FIGURE 2 Stepwise polycentricity (SP) trajectories and identified urban centers for Shenzhen, Tianjin, and Wuhan in 2002 and 2019. The main centers are indicated in red, and the subcenters are in blue.

one. However, a closer examination reveals a subtle shift toward polycentricity, as indicated by the higher SP trajectory in 2019 (illustrated in purple) in comparison to 2012, particularly when considering the SP indices of the top several centers. This nuanced shift, not adequately captured by the SP typology, underscores the necessity of the CP index as an additional analytical measure of polycentricity. Throughout the study, Wuhan consistently exhibited a polycentric (G3) pattern, with the SP indices of its top two centers exceeding 1 in both years. This persistent polycentric nature of Wuhan is further substantiated by its geographic division by the Yangtze River into two major centers, Hankou and Wuchang.

3 | THE EVOLUTIONARY PATTERNS OF URBAN SPATIAL STRUCTURE FOR CHINESE CITIES

3.1 | The evolutionary patterns based on the SP typology

Our analysis starts with an investigation of the evolutionary patterns of urban spatial structure across 269 Chinese prefectural cities, categorized into three typologies: monocentric (G1), multicentric (G2), and polycentric (G3). We further identify nine distinct scenarios of urban structural change by comparing the SP typologies from 2002 to 2019 for each city. These scenarios are subsequently aggregated to indicate whether cities present an "unchanged" status, a trend of "increasing polycentricity," or a trend of "decreasing polycentricity" (as detailed in

Table 2). Cities in the "unchanged" category retain a consistent urban structure across both time points, including the scenarios of G1→G1, G2→G2, and G3→G3. The “increasing polycentricity” category indicates a significant trend toward polycentricity, including transitions of G1→G2, G1→G3, and G2→G3. Notably, the transition G1→G2 is considered an increase in polycentricity because it suggests the emergence of at least one subcenter in a previously single-centered city. Cities classified under “decreasing polycentricity” demonstrate a trend toward a more monocentric pattern, including the transitions G3→G2, G3→G1, and G2→G1. The shift G3→G2 is interpreted as a decrease in polycentricity because it suggests a less evenly distributed urban growth, with the urban core growing more rapidly than any subcenter. A complete list detailing the evolutionary patterns of the 269 Chinese prefectural cities is provided in the Supporting Information S1.

According to the Sankey map (Figure 3) and the data presented in Table 2, we can draw two preliminary conclusions concerning the scenarios of urban structure evolution. First, the trend toward a multicentric (G2) rather than polycentric (G3) pattern dominated the evolution of Chinese cities from 2002 to 2019. In 2002, 140 cities exhibited a multicentric (G2) pattern, a number that increased to 188 by 2019, constituting nearly 70% of the examined prefectural cities. In contrast, the number of monocentric (G1) and polycentric (G3) cities underwent a decline. Only 63 cities were monocentric (G1), and 66 were polycentric (G3) in 2002; these

TABLE 2 Evolutionary patterns of urban spatial structure from 2002 to 2019 based on SP typology, aggregated into “unchanged,” “increasing polycentricity,” and “decreasing polycentricity” groups.

Unchanged cities		**Increasing polycentricity**		**Decreasing polycentricity**	
Scenario	***N***	**Scenario**	***N***	**Scenario**	***N***
G1→G1	27	G1→G2	33	G3→G2	32
G2→G2	124	G2→G3	14	G2→G1	2
G3→G3	33	G1→G3	3	G3→G1	1
Total	184	Total	50	Total	35

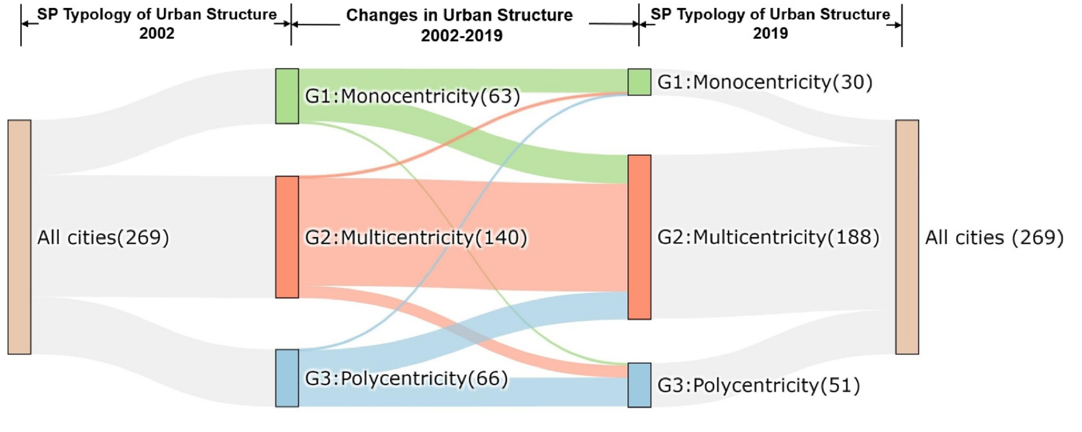


FIGURE 3 Evolutionary patterns of urban spatial structure in 269 Chinese prefectural cities from 2002 to 2019, categorized by the SP typology.

figures decreased to 30 and 51, respectively, by 2019. In terms of the evolutionary patterns, 33 monocentric (G1) and 32 polycentric (G3) cities transitioned to a multicentric (G2) pattern, outlining two major evolutionary trends across all scenarios.

The coexistence of tendencies in both directions and the various associated scenarios (as seen in Table 2) suggest a rather diverse and intricate evolutionary pattern. The 50 cities marked as “increasing polycentricity” consisted of 33 cities that transitioned from G1 to G2, 14 from G2 to G3, and 3 from G1 to G3. The emergence of subcenters in the previous monocentric cities (G1→G2) represented the primary pathway toward polycentricity. In comparison, of the 35 cities exhibiting a “decreasing polycentricity” pattern, 32 transformed G3 to G2, 2 moved from G2 to G1, and 1 from G3 to G1. The primary pathway toward increasing monocentric was the transition from a polycentric to a multicentric pattern (G3→G2).

Figure 4 and Table 3 comprehensively analyze the evolutionary patterns of urban structure based on city size. Following the city-size classification guidelines proposed by the central government of China, cities are categorized into three groups: (a) large cities with an urban population exceeding 5 million (25 out of 269), (b) medium-sized cities with an urban population ranging between 1 and 5 million (115 out of 269), and (c) small-sized cities accommodating an urban population under 1 million (129 out of 269).

In 2002, nearly all large cities (24 out of 25) and a significant portion of medium-sized cities (69 of 115) exhibited a multicentric (G2) pattern. Small cities displayed greater diversity, with 44 in G1, 47 in G2, and 38 in G3. Throughout the study period, there was a noticeable trend toward multicentricity (G2) in both medium- and small-sized cities. This shift primarily stemmed from two evolutionary patterns, G1→G2 and G3→G2, which collectively accounted for structural transformations in 65 medium- and small-sized cities. Moreover, the transition from G3 to G2 observed in 32 medium- and small-sized cities suggests that a polycentric configuration is not exclusive to large cities. A smaller city may initially exhibit a polycentric (G3) pattern and subsequently evolve toward a multicentric (G2) pattern due to the growth of the city's main center.

From a dynamic perspective, large cities showed considerable spatial structural stability from 2002 to 2019, with 23 cities maintaining an “unchanged” status. Only two large cities—Shenzhen and Foshan—transitioned from G2 to G3. Among medium-sized cities, 21 demonstrated a trend toward polycentricity, while 20 transitioned from G3 to G2, suggesting a decrease in polycentricity. Similarly, in small-sized cities, 28 exhibited a tendency toward polycentricity,

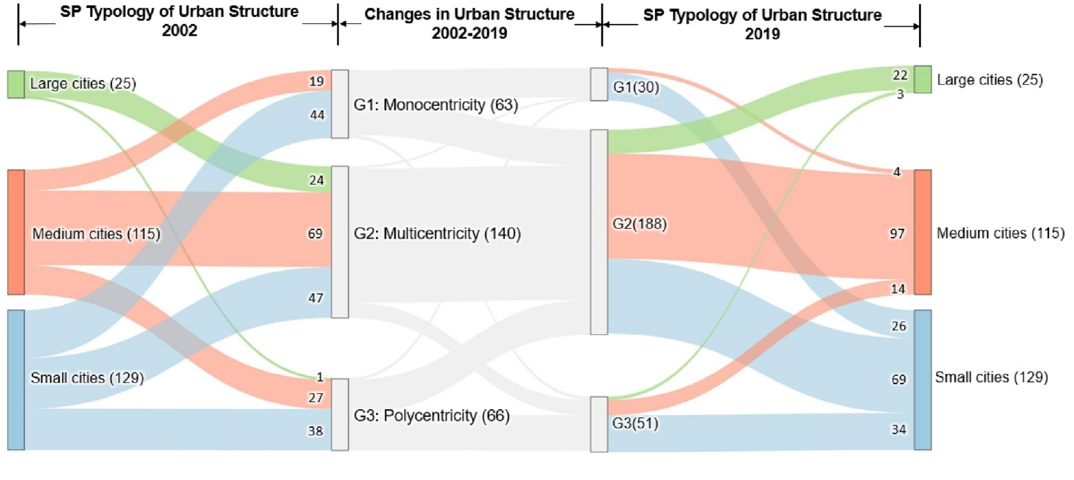


FIGURE 4 Evolutionary patterns of urban spatial structure in large, medium, and small cities, 2002–2019.

TABLE 3 Scenarios of evolutionary patterns in urban spatial structure, 2002–2019, categorized based on the SP typology and size of cities.

Large cities (25 cities)			**Medium cities (115 cities)**			**Small cities (129 cities)**		
Scenario	***N***	**Category**	**Scenario**	***N***	**Category**	**Scenario**	***N***	**Category**
G2→G2	22	Unchanged	G2→G2	63	Unchanged	G2→G2	39	Unchanged
G3→G3	1		G3→G3	7		G3→G3	25	
Total	23		G1→G1	4		G1→G1	23	
			Total	74		Total	87	
G2→G3	2	Increasing polycentricity	G1→G2	14	Increasing polycentricity	G1→G2	19	Increasing polycentricity
Total	2		G2→G3	6		G2→G3	6	
			G1→G3	1		G1→G3	3	
			Total	21		Total	28	
			G3→G2	20	Decreasing polycentricity	G3→G2	12	Decreasing polycentricity
			Total	20		G2→G1	2	
						G3→G1	1	
						Total	15	

while 15 showed a trend in the opposite direction. These findings highlight the heterogeneous evolutionary pathways of urban structure across Chinese cities, characterized by the concurrent trends toward and away from a polycentric configuration, a phenomenon particularly prevalent in medium and smaller cities.

3.2 | An examination of the “unchanged” scenarios using the CP index

A noteworthy observation from our analysis is that 184 cities, representing 68% of the total, were categorized as “unchanged,” maintaining a stable urban configuration throughout the study period. However, labeling these cities as entirely static would be an oversimplification, as micro-scale changes in urban structure likely occurred, reflecting local spatial developments. Given this concern, we further analyzed the nuanced shifts within this “unchanged” group, focusing on scenarios of G2→G2 and G3→G3 using the CP index. The boxplots in Figure 5 reveal that 22 large cities in the G2→G2 scenario experienced a moderate rise in polycentricity from 2002 to 2019, indicated by higher median values of the CP index denoted by the red horizontal lines. By comparison, the 63 medium-sized and 39 small-sized cities in the G2→G2 scenario exhibited a decline in polycentricity over the same period. Comparable trends emerged in the G3→G3 scenario across cities of varying sizes. This included a notable increase in the degree of polycentricity for the large city of Wuhan and a prevalent decline for 7 medium- and 25 small-sized cities during the study period.

By now, we have comprehensively examined the evolution of urban structure across 269 Chinese cities using two reliable polycentricity measures. Our observations suggest a tendency toward polycentricity in larger cities, demonstrated by a moderately increasing polycentricity for the 22 cities (as measured by the CP index) and a significant transition from a multicentric (G2) to a polycentric (G3) pattern in Shenzhen and Foshan (as measured by the SP typology).

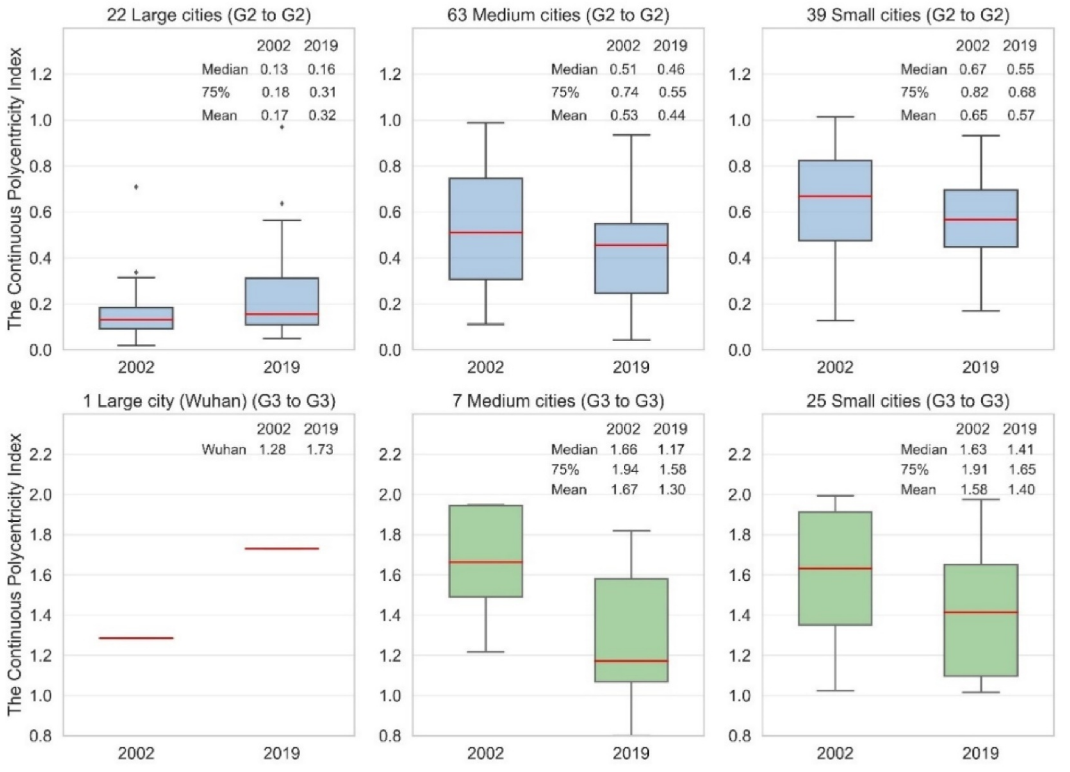


FIGURE 5 Boxplots of continuous polycentricity (CP) indices of large-, medium-, and small-sized cities for G2→G2 (first row) and G3→G3 (second two) scenarios based on top 2 centers. G3→G3 scenario includes only one large city, Wuhan.

Such a ubiquitous trend toward polycentricity highlights significant residential decentralization and relocation toward burgeoning subcenters in these cities. However, the evolutionary trajectories of medium- and small-sized cities display considerable diversity. According to the SP typology, 48 medium- and small-sized cities demonstrated a tendency toward polycentricity. Meanwhile, declining polycentricity existed among a wide set of medium- and small-sized cities, including 134 cities in scenarios of G2→G2 and G3→G3 that underwent a moderate decrease in polycentricity measured by the CP index, 32 cities that transitioned from G3 to G2, and a few others from G2 to G1 as identified by the SP typology. This pervasive decrease in polycentricity among smaller cities suggests a continued and growing importance of the urban core in comparison to subcenters.

4 | THE INTERPRETATION OF THE EVOLUTION OF URBAN SPATIAL STRUCTURE

4.1 | Polycentricity, population, and economic growth

The evolutionary pathways of spatial structures are influenced by demographic, economic, transportation, and political factors, as well as the initial configuration of the urban system. Of the factors at play, population and economic growth stand out as crucial determinants, closely intertwined with the locational decisions of individuals, households, and firms (Bartosiewicz & Marcinczak, 2022). Additionally, government regulations related to migration, regional economies, and real estate markets play a significant role (Jia et al., 2020). However, quantifying these policies presents a challenge due to their varied development and implementation across different cities. Disentangling the effects of market forces and governmental interventions further adds complexity, as policies often indirectly shape urban structure by lifting constraints imposed on the market (Li & Derudder, 2022). Considering these data and methodological limitations, our approach included a comparative analysis to examine the associations between polycentric configuration, population, and economic growth. We then used qualitative methods to interpret the influence of government policies and local-specific factors on the diverse evolutionary trajectories of spatial structures.

The comparative analysis utilizes the mean-comparison *t*-test to assess whether the population and GDP per capita for each selected scenario significantly deviate from the reference scenario, G2→G2, chosen for its stability in urban structure throughout the study. Our analysis focuses on six scenarios: G2→G2, G1→G1, G3→G3, G1→G2, G2→G3, and G3→G2. The other three, G1→G3, G2→G1, and G3→G1, are excluded due to limited observations. Given their similar spatial-temporal trends in spatial structure, medium- and small-sized cities are grouped together to facilitate comparison. Table 4 shows that GDP-related comparisons did not yield

TABLE 4 Population and GDP per capita levels in 2019 and growth rates from 2002 to 2019 across six scenarios: G2→G2, G1→G1, G3→G3, G1→G2, G2→G3, and G3→G2.

	Reference group					
Cities	**G2→G2**	**G1→G1**	**G3→G3**	**G3→G2**	**G1→G2**	**G2→G3**
Panel A						
Total population 2019						
Large city	12,701	-	-	-	-	11,435
Medium & small city	4842	2172-**	3349-**	4189-*	3673-**	3721-*
Growth rate of population 2002–2019						
Large city	1.37	-	-	-	-	1.84+*
Medium & small city	1.06	1.29+*	1.05	1.19+**	1.15+*	1.11
Panel B						
GDP per capita 2019						
Large city	110,285	-	-	-	-	137,398
Medium & small city	58,091	57,603	56,656	59,006	61,212	52,900
Growth rate of GDP per capita 2002–2019						
Large city	5.44	-	-	-	-	4.34
Medium & small city	7.36	8.58+*	8.03	7.61	8.38	7.33

Note: Reference group: G2 to G2. (1) The unit of population is a thousand people, and the unit of GDP per capita is RMB. (2) The growth rate is defined as the value in 2019 divided by the value in 2002. (3) Data source: the CEIC database and the statistical yearbooks of prefectural cities of China.

p-value is significant at $^{*}p < 0.05$, $^{**}p < 0.01$.

significant differences, except the G1→G1 scenario, which offers limited insight into the debates on polycentricity. For population trends, the analysis reveals that large cities in the G2→G3 scenario experienced a notably higher growth rate (1.84) compared to the reference scenario (1.37). As for small- and medium-sized cities, the reference scenario (G2→G2) consistently exhibits a significantly larger population than other scenarios. In terms of population growth rates, the rate in the reference scenario (1.06) is significantly lower than those observed in the scenarios of G3→G2 (1.19), G1→G2 (1.15), and G1→G1 (1.29).

The statistically significant results suggest a positive correlation between population growth and two evolutionary trends: a shift toward polycentricity in large cities and toward multicentricity in small- and medium-sized cities. Closer scrutiny of the move to multicentricity reveals that population growth is associated not only with the emergence of subcenters in previously monocentric cities (G1→G2) but also with a decrease in polycentricity in formerly polycentric cities (G3→G2). Notably, a decrease in polycentricity, as observed in the G3→G2 scenario, should not be interpreted as indicative of a city's decline or shrinkage; rather, it reflects a greater prominence of the urban core relative to the subcenters, particularly in smaller cities.

4.2 | Polycentricity, governmental policy, location-specific factors

In this section, we explore the influence of governmental policies and location-specific factors on cities that have experienced significant changes in spatial structure. The widespread trend toward polycentricity in the 25 large cities indicates a trend of decentralization, evidenced by the increasing relocation of residents to emerging subcenters, likely in response to enhanced transit systems and soaring housing costs in urban cores. Emerging subcenters are playing an increasingly vital role in managing urbanization, thereby diminishing the relative importance of the urban core. Data presented in Column 1 of Table 3 highlights this shift, which shows that subcenters have experienced a remarkable population growth of 227.91% from 2002 to 2019, substantially outpacing the 65.99% growth observed in urban cores. Furthermore, the emergence of an average of 5.44 additional subcenters, as shown in Figure 6a, further supports the trend toward a more decentralized and polycentric urban configuration in large cities.

Over recent decades, policy-driven strategies aimed at establishing or nurturing functional new districts have become increasingly common. A notable example is found in the Shanghai city master plan, which promotes the establishment of multiple industrial and residential subcenters in the hinterlands to alleviate agglomeration inefficacies in the traditional urban core (Shanghai Municipal Government, 2017). Similarly, Tianjin's master plan advocates for a nested polycentric pattern aimed at fostering more balanced and coordinated regional growth (Wang et al., 2020). A notable policy within this context is relocating city halls to burgeoning districts and subcenters, a strategy intended to stimulate the local housing market and boost employment (Deng, 2024; Zhao et al., 2022). Iconic examples include Beijing, Xi'an, Chengdu, and Shenyang. By the end of 2014, China had established over 3,000 new districts and subcenters at the county level or higher (Feng, 2015). Among these, the national-level special economic districts (*Guojiaji Xinqu*) have been particularly influential in driving local economic growth. Supported extensively by the central government in land acquisition, infrastructural development, and financing (Martinez, 2018), these districts aim to attract investment, encourage economic restructuring, and promote technological innovation. By 2019, 11 of the 19 national-level new districts had been established in major cities, each having an outsized impact

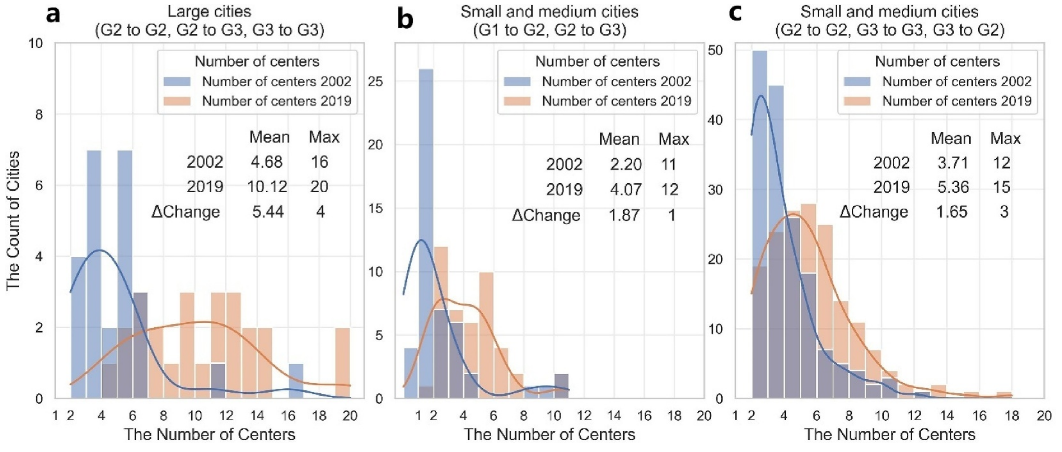


FIGURE 6 The number of identified centers in 2002 and 2019 by city size and scenarios of urban spatial structure evolution.

on the urban spatial structure of these cities. An example is provided in Figure 7a,b, which contrasts urban development in Dalian city on the east coast of China between 2002 and 2019. The rapid expansion of the Jingpu New District, relative to the city's main center, has played a crucial role in shaping the city's polycentric pattern. This pattern of spatial development toward polycentricity is similarly observed in other large cities, such as Tianjin and Nanjing.

In small- and medium-sized cities, the trend toward polycentricity manifests in the transition from monocentric to multicentric patterns (G1→G2) and from multicentric to polycentric patterns (G2→G3). Echoing the trend in larger cities, small- and medium-sized cities have also undergone extensive population decentralization, characterized by the disproportionately higher population growth rates in subcenters (279.74%) compared to main centers (46.59%), as shown in Column 2 of Table 5. On average, each city has seen 1.87 subcenters emerge between 2002 and 2019 (Figure 6b). In certain instances, the increase in the degree of polycentricity is not only due to population growth but also to the rapid development of county-level cities. These cities usually hold higher administrative authority, greater autonomy, and better development opportunities than ordinary county-level entities within a prefectural administrative unit. Puning, a county-level city with a population of 2.5 million, accounts for 45% of the total population of its associated prefectural city as of 2019. This significant demographic contribution positions Puning as a typical example of how county-level cities can influence urban spatial structure. Another factor contributing to the increased polycentricity in small- and medium-sized cities is the establishment of numerous functional new districts to attract manufacturing industries, promote local employment, and serve as new local economic hubs. A compelling illustration is the Yingkou prefectural city in northeast China (Figure 7c,d), where the transformation toward a polycentric structure was driven by the emergence of its economic zone and the expansion of the county-level city, Gaizhou. Similar urban spatial patterns have been observed in other cities, such as Datong, Zhanjiang, Dezhou, Taizhou (Jiangsu), and Hechi, where the degree of polycentricity increased for comparable reasons.

The majority of medium- and small-sized cities display a trend of declining polycentricity, as demonstrated by the 32 cities that transitioned from G3 to G2, along with a large set of cities that experienced a moderate decline in polycentricity within the G2→G2 and G3→G3 scenarios. A closer investigation of these cities reveals that the rapid population growth of cities' urban

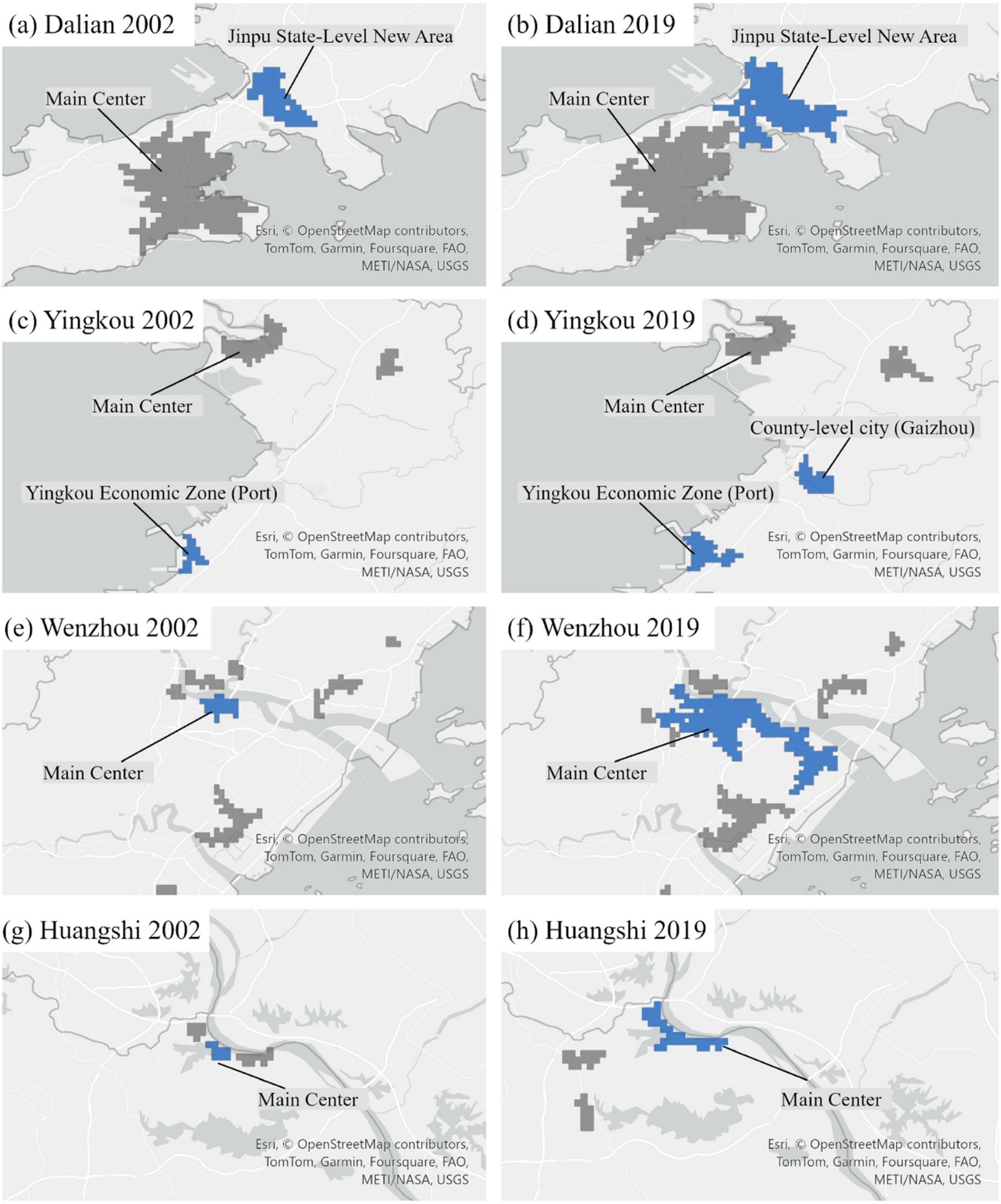


FIGURE 7 Urban core and subcenters identification in four Chinese prefectural cities. (a, b): Dalian, (c, d): Yingkou, (e, f): Wenzhou, (g, h): Huangshi.

core relative to subcenters is crucial for these cities to become more monocentric. Population statistics in Column 3 of Table 3 suggest a 67.81% increase in the main centers, surpassing the 46.59% growth in cities with increasing polycentricity. Meanwhile, subcenters' population growth, at 80.36%, though marginally higher than that of main centers, is significantly lower than the 279.74% increase seen in their polycentric counterparts. These findings suggest that many small- and medium-sized Chinese cities have experienced moderate decentralization,

TABLE 5 Population statistics for main centers and subcenters by city size and scenarios of urban spatial structure evolution.

City Count of cities Scenarios	Column 1 Large city; increasing polycentricity 25 cities G2→G2 (22) G3→G3 (1) G2→G3 (2)	Column 2 Small & medium cities; increasing polycentricity 45 cities G1→G2 (33) G2→G3 (12)	Column 3 Small & medium cities; decreasing polycentricity 166 cities G2→G2 (102) G3→G3 (32) G2→G3 (32)
2002			
Main center population	2,150,381	323,214	362,312
Subcenters population	452,012	80,459	252,311
2019			
Main center population	3,567,957	473,794	608,011
Subcenters population	1,482,175	305,535	455,072
Growth rate of population (2002–2019)			
Main center population (%)	65.99%	46.59%	67.81%
Subcenter population (%)	227.91%	279.74%	76.56%

Note: (1) Population statistics are based on Landscan dataset in 2002 and 2019. (2) This table summarizes the population statistics of 236 cities. Scenarios of G1→G1 and those for medium and small cities with too few samples are excluded. The population statistics reported are mean values.

with migration toward emerging subcenters. However, in contrast to polycentric cities, their decentralized patterns are less pronounced, and the dominant role of main centers continues to strengthen. An illustrative example is Wenzhou, a prefectural city in southeast China. Displaying a polycentric pattern in 2002 due to historical and geographical factors, Wenzhou evolved into a monocentric city as its main center significantly expanded over the past two decades (as depicted in Figure 7e,f). A similar growth pattern is observed in 20 of the 32 cities[3] within the G3→G2 scenario. Another common reason for decreasing polycentricity is illustrated by the prefectural city of Huangshi in Figure 7g,h, where three distinct urban centers in 2002 expanded and eventually merged, culminating in a new dominant urban core by 2019. This fusion mode is apparent in 10 of the 32 cities within the G3→G2 scenario.

5 | A STYLIZED FRAMEWORK OF EVOLUTIONARY PATTERNS OF URBAN SPATIAL STRUCTURE

This analysis reveals the existence of diverse and intricate evolutionary trajectories within the urban spatial structure of Chinese prefectural cities. To comprehensively illustrate these dynamic patterns, we proposed a stylized framework that delineates three progressive stages of urban structural evolution based on the size of cities. As sketched out in Figure 8, the urban spatial configuration of a small city in its initial phase can assume various forms (G1, G2, G3),

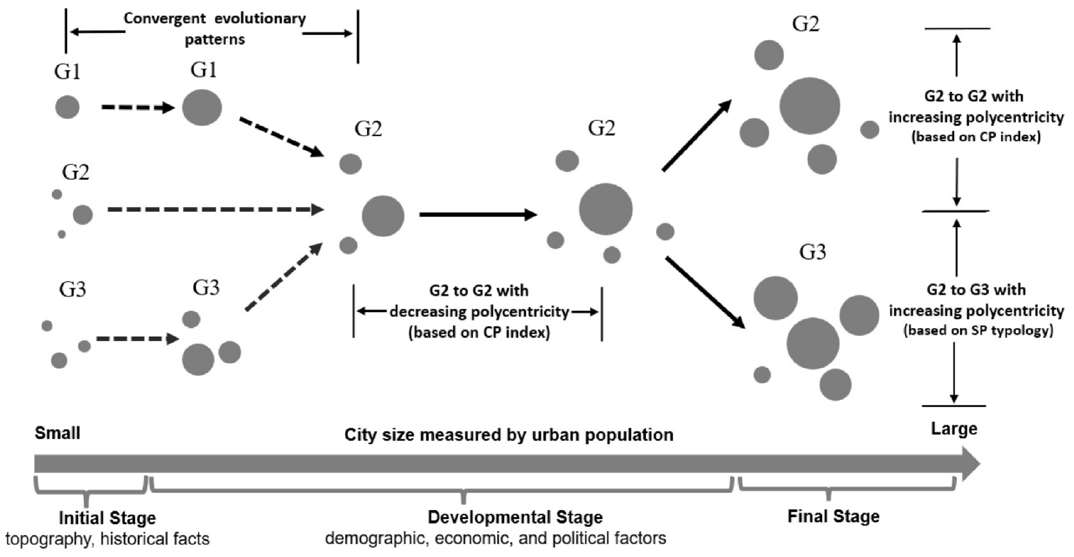


FIGURE 8 Stylized framework illustrating the evolutionary patterns of urban spatial structure of Chinese cities.

influenced by historical path, contextual factors, and geographical barriers such as the existence of mountains, lakes, and rivers (Bartosiewicz & Marcinczak, 2022; Liu & Wang, 2016). As cities develop, three distinct pathways materialize.

The first pathway pertains to cities that initially exhibited a single center and underwent the gradual emergence of subcenters, influenced by demographic, economic, and political factors. Examples of this include the 33 small- and medium-sized cities that transitioned from a single-centered to a multicentric (G1→G2) pattern, as identified in our analysis. Arribas-Bel and Sanz-Gracia (2014) documented a similar trajectory toward polycentricity in 45 U.S. metropolitan areas from 1990 to 2010. The second pathway illustrates cities with an original polycentric structure (G3) that transition toward a multicentric pattern, driven by the incorporation of a main center over smaller subcenters or by the fusion of several independent centers of equivalent size. We recognized 32 small- and medium-sized cities that follow this trajectory (G3→G2), as the influx of migrants into the city main center exceeds that of any subcenters. The third pathway includes small- and medium-sized cities that maintain a consistent multicentric pattern (G2→G2) for the duration of the study. This is the most common type, characterized by the simultaneous growth of the main center and subcenters.

During the development stage, all three pathways converge in the form of multicentric cities (G2), characterized by the emergence of subcenters alongside the expansion of the urban core. Within this stage, although cities maintain an overall multicentric (G2) configuration, nuanced variations exist that nudge them toward a more monocentric pattern due to the faster growth of the urban core relative to the subcenters. This can be attributed to the fact that for small- and medium-sized cities, the advantages derived from agglomeration economies tend to outweigh the agglomeration diseconomies, such as soaring housing prices and congestion-related costs. Our analysis substantiated this trend by demonstrating a moderate decline in the degree of polycentricity among small- and medium-sized cities within the G2→G2 scenario, as displayed in Figure 5, evaluated using the CP index.

The discernible increase in the degree of polycentricity for large cities suggests that agglomeration diseconomies have surpassed the agglomeration benefits generated by the urban core. This trajectory is supported by the moderate increase in polycentricity observed across 22 large cities, and the shift from G2 to G3 in 2 large cities, Shenzhen and Foshan. While an overall trend toward polycentricity is evident, a substantial proportion of these cities continue to exhibit a multicentric (G2) pattern. This explains the coexistence of G2 and G3 patterns within the current stage and the foreseeable future. Notably, our stylized framework intentionally excludes certain scenarios, as our objective is not to exhaustively consider all possible scenarios but rather to present a generalized understanding of the evolutionary patterns of Chinese prefectural cities. We have excluded the scenarios of G2→G3, G1→G3, G→G1, G3→G1 for small- and medium-sized cities, a total of 18 cities. We believe the exclusion of these specific cases does not compromise the generalizability of our analysis.

6 | CONCLUSION

This study investigates the spatial-temporal evolution of urban spatial structure across 269 Chinese prefectural cities from 2002 to 2019, utilizing two reliable polycentricity measures. We discussed potential explanations for the emergence or absence of polycentric spatial configuration through comparative analysis and qualitative map interpretations. Our analysis suggests a diverse range of evolutionary pathways related to polycentricity, in contradiction with the commonly held understanding that Chinese cities are ubiquitously becoming more polycentric. Specifically, we observed a general trend toward polycentricity in the 25 largest cities. Among them, 22 cities exhibited a moderate increase in polycentricity, as identified by the CP index, and 2 cities, Shenzhen and Foshan, transitioned from a multicentric to a polycentric pattern. Population growth and policy incentives are important factors that lead large cities to polycentric and decentralized urban spatial patterns.

In contrast to large cities, evolutionary patterns across small- and medium-sized cities are rather diverse and complex, with some becoming more polycentric while the majority remain monocentric. The trend toward polycentricity manifests through the emergence of subcenter(s) in previous single-centered cities (G1→G2) and the transformation from a multicentric to a polycentric pattern (G2→G3). The emergence of subcenter(s) is associated with a higher population growth rate. The transition toward polycentricity (G2→G3) is primarily influenced by political factors and spatial planning policies, such as the growth of county-level cities and the establishment of economic zones and functional districts. Decreasing polycentricity among small- and medium-sized cities is substantiated by a decline in the CP index for cities in the "G2→G2" and "G3→G3" scenarios, along with the transition of cities from a polycentric to a multicentric configuration (G3→G2). Our comparative analysis finds a positive relationship between population growth and the G3→G2 scenario, suggesting consistent growth in the urban core compared with the subcenters. We should emphasize that decreasing polycentricity should not be interpreted as a declining or shrinking city; instead, it indicates a concentration of both residents and migrants in the urban core. Greater population density can attract firms and create more job opportunities, thereby strengthening the agglomeration economies of the city. The same scenario also applies to the wide set of "unchanged" cities, where a more concentrated population distribution contributes to a stronger main center, bringing about higher agglomeration benefits.

The findings have several implications for the spatial planning policy of Chinese prefectural regions that comport with our hypotheses. First, the fact that mega-cities in China have generally evolved into more polycentric configurations suggests that polycentrism could be an effective policy instrument to mitigate agglomeration diseconomies and produce more sustainable urban patterns. This implies that subcenters can not only serve to accommodate growth but also function as local economic hubs, drawing in firms and investments while offering employment opportunities. For most small- and medium-sized cities, we submit that the trend of moderately decreasing polycentricity, characterized by a more concentrated population density in the urban core, represents an economically efficient spatial development pathway for these cities, allowing for the growth associated with agglomeration economies. For the cities that transitioned from a multicentric to a polycentric pattern (G2→G3), their economic performance should be carefully investigated to assess whether polycentrism has produced an overly dispersed urban pattern hindering agglomeration growth. Moreover, in such scenarios, emerging subcenters might not derive any functional or performance benefits from the nearby urban core, especially if the core is too small to support the development of subcenters. In these cases, subcenters should strive for self-sustainability by specializing in appropriate industrial sectors, capitalizing on their location, resources, or political advantages, and offering urban and natural amenities to attract skilled workers. To sum up, the development and implementation of regional spatial policy should be tailored to consider the diverse sizes of cities, their unique historical paths, and contextual factors.

We acknowledge the limitations inherent in our analytical methods. First, the group comparison analysis does not allow us to add control variables, and the existence of omitted variables may explain why the levels and growth rates of GDP per capita are insignificant in the group comparison analysis. Moreover, we qualitatively explained the influence of governmental policies on urban structure, primarily due to the difficulty in collecting and quantifying these policies. Further analysis may quantify the political factors and utilize regression analysis to comprehensively explore the reasons for urban structural evolution. Finally, the role of population growth in driving urban spatial patterns, and the reliance on using population change as an explanatory variable for urban spatial structure may not hold in the future, as China faces an overall population decline. This will have profound impacts on both governmental policies that until recently have been primarily focused on accommodating and decentralizing growth, and on real estate development and the housing market more broadly. Evolutionary pathways of regional structure may look quite different in an era of population decline.

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CONFLICT OF INTEREST STATEMENT

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Wenzheng Li https://orcid.org/0000-0003-2895-5434
Stephan Schmidt https://orcid.org/0000-0003-2412-3868

ENDNOTES

[1] Some studies refer prefectural-level administrative units as prefectural city regions (Sun et al., 2019) or prefectural regions (Li et al., 2019). This study use the term "prefectural city" following the works of Li and Derudder (2022) and Liu and Wang (2016).

[2] The rank-size distribution of centers in a prefectural city following the Zip's Law indicates that the population size of the *n*th center is equal to $1/n$ of the population size of the largest center, where n represents the rank of city center sorted by population size in descending order.

[3] These cities include Baoshan, Chaoyang, Chaozhou, Fuyang, Guigang, Hanzhong, Jinzhong, Liaocheng, Linfen, Ma'anshan, Mianyang, Qingyuan, Qujing, Shiyan, Shizuishan, Wenzhou, Yangjiang, Jining, Huizhou, and Taizhou (Zhejiang).

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SUPPORTING INFORMATION

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