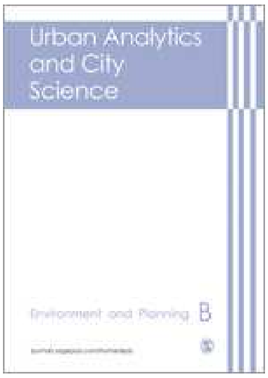

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Title: Measuring polycentric structures of megaregions in China: Linking morphological and functional dimensions

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Abstract

The idea of megaregions, which focuses on polycentricity, competiveness and integration, attracts much attention in research and policy. China has used megaregions as a normative governance framework that leverages polycentric regional development for balancing economic competitiveness and spatial development. This paper explores to what extent these megaregions actually reveal polycentric versus monocentric structures. The analysis demonstrates a divergence between the morphological and functional organization of China's megaregions. Five types of megaregions are identified as per the relationships between the morphological and functional dimensions. Functionally, the Pearl River Delta, Shandong Peninsula, and Yangtze River Delta are among the most polycentric megaregions. The majority of others, even where morphologically polycentric, do not exhibit high degrees of functional polycentricity. The study demonstrates a problematic nature of megaregions as a governance agenda for regional polycentricity. It argues that if China genuinely wants to achieve greater levels of polycentricity and spatial cohesion, differentiated policies should be implemented for megaregions.

Keywords: Megaregion; Polycentricity; Spatial structure; City network; China

Measuring polycentric structures of megaregions in China: Linking morphological and functional dimensions

1. Introduction

Over the past few decades, polycentricity has emerged as a high-referenced vocabulary in urban and regional research and practice. However, it also remains one of the most ambiguous concepts. As Li and Phelps (2017) have pointed out, the ambiguity stems from the fact that polycentricity changes its meanings in application to different geographical scales, as it also does from different analytical perspectives. For example, polycentricity can be applied to the intra-urban, inter-urban, inter-regional scale, but "polycentricity at one scale may be monocentricity at another" (Nadin and Dühr, 2005: 82).

One scale which has recently attracted particular attention is that of megaregions - usually identified (albeit still with certain ambiguity) as a polycentric agglomeration of two or more networked metropolitan areas and their hinterlands. Many believe that megaregions become the key organizing nodes for the globally networked world economy, producing a large part of economic wealth and innovation (Florida, Gulden, & Mellander, 2008). Megaregions are argued to produce synergetic effects between their constituent urban nodes. In this reading, megaregions generate many kind of "goodies" – from greater agglomeration externalities, to economic synergy and specialization, to social and spatial cohesion and enhanced environmental sustainability (Meijers and Burger, 2010; Veneri, 2010). No wonder, policy makers and urban planners start promoting them as a planning agenda (Davoudi, 2003; European Commission, 1999; Regional Plan Association, 2006; Sorensen, 2001; Veneri & Burgalassi, 2012).

The concept of polycentric megaregion has also attracted attention in academic and policy debates in China, where the coastal megaregions of Yangtze River Delta and the Pearl River Delta are already acknowledged as globally competitive megaregions. After "urban agglomeration" was recognized as a planning unit in China's 11th Five-Year Plan of 2006, polycentric megaregions have formed a new normative territorial vision that seeks a more coordinated and balanced development of cities of different size.[1] Various studies have explored the polycentricity character of existing megaregions to support such policies (Li and Wu, 2013; Gao, Huang, He & Dou, 2017). However, existing literature focuses on either morphological polycentricity or functional polycentricity. Moreover, studies are usually confined to a few particular coastal megaregions. It is in this sense that Liu et al. (2016) argued that a partial and fragmented understanding may create a vicious cycle of misconception and ill-informed policies.

Our paper, in contrast, takes into account *all* megaregions in China and provides a relative analysis of their morphological and functional polycentricity. One fundamental research agenda is whether the megaregional process is a consequence of polycentric development, or is being driven by a monocentric spatial organization. We evaluate the actual conditions of spatial polycentricity underpinning China's megaregions policy in order to identify possible priorities if China wants to build polycentric megaregions. We thus make several important

[1] In China, chengshiqun (城市群) is used to identify the urbanization landscape of agglomerative integration of several metropolitan systems and their hinterlands (rather than a single urban system). This has been variously translated into English as 'urban agglomerations' or 'urban clusters' rather than megaregions. However, the term "megaregion" is increasingly used as more suited to describe the phenomenon, especially given the vast regional extent of the associated units identified in planning and academic literature.

contributions. Firstly, the paper comprehends the whole profile of Chinese megaregions in morphological and functional dimensions by combining attribute data and relational data. Secondly, it develops a generalized methodological framework to measure and compare morphological and functional features of polycentricity, which may be replicable in other studies. Thirdly, the paper explores to what extent the development of megaregions may be considered polycentric and what further implications this has for spatial governance and normative regimes of regional development.

The paper is organized as follows. We start with reviewing megaregion ideas in China's policies. We then present our methodology for analyzing the polycentric patterns in China's megaregions, including morphological and functional polycentricity indexes. We then explore to what extent each of 20 megaregions is polycentric in both the morphological and functional domains. Based on the relationships between these two dimensions – morphological and functional – we develop a typology of megaregions and identify five distinctive types of megaregions. We then discuss each of the five types in more details, before providing overall implications.

2. The emergence of normative megaregions

2.1 Polycentricity and megaregions

The notion of polycentricity has been applied to varied spatial formations, with different definitions, measurements and interpretations used to understand polycentricity (Hall & Pain, 2006; Kloosterman & Musterd, 2001; Scott, 2002; Taylor, Evans, & Pain, 2008; Taubenbock & Wiesner, 2015). There consequently remain many unsolved issues, both conceptually and methodologically. For example, as a concept denoting decentralized concentration, polycentricity is usually believed to include morphological and functional dimensions (Burger & Meijers, 2012). Originally, polycentricity was predominantly associated with a *morphological* dimension, implying a territorial distribution of urban nodes in the absence of a dominant center (Meijers, 2008). However, research on polycentricity has become increasingly concerned with a *relational* approach that focuses on functional linkages between different centers or nodes, such as flows of goods, labor, capital or knowledge (Burger, van der Knaap, & Wall, 2014). Based on the network paradigm, proponents of the functional polycentricity approach argue that an urban system lacking a balanced distribution of functional relations between its nodes cannot be regarded polycentric even if it is such morphologically. However, the morphological and functional polycentricity are usually considered as two distinctive analytical categories as they employ distinct types of data - namely attribute data or flow data - which may lead to different results. Measurements of polycentricity tend to focus on either of these routes (Burger and Meijers, 2012; Liu, Derudder, & Wu, 2016). Consequently, the relationship between these two dimensions appears to be unclear.

The concept of megaregion further challenges existing theories of regional development and integration (Harrison, 2013; Ross, 2009). The concept of megaregion as a polycentric urban system is often traced to Gottmann (1957, 1961) and his analysis of megalopolis as a 'laboratory for urban growth' (cf. Baigent, 2004). Today, megaregions are understood as a form of agglomerative integration of several metropolitan systems and their hinterlands in an economically and ecologically coalesced spatial system, parts of which engage in daily transactional movements of capital, people, material and services (Florida, Gulden, & Mellander, 2008; Meijers, 2005). Compared to concepts such as urban/city region, a megaregion is comprised of two or more interrelated metropolitan areas rather than a single urban system centered on a dominant city. These areas are physically linked by transportation, telecommunication and other infrastructural networks, as well as by their functional economic conditions.

As Harrison and Hoyler point out (2015a, 2015b), megaregions represent a nexus of localization and globalization. As super-spatial-agglomerations, combining the benefits of agglomerative clustering and economic specialization, megaregions encapsulate the leading-edge capitalist endeavor, drive competitiveness and determine the opportunities of growth (Florida, Gulden, & Mellander, 2008). A large number of studies have identified the existence and extent of megaregions on all inhabited continents.

2.2 Polycentric megaregion plans in China

Since the beginning of China's opening up policy in 1978, the country has experienced an unprecedented pace of urbanization. In 1978, 170 million people lived in cities (18% of the national population), while by 2013 the urban population has researched 731 million (54%). While contributing to economic growth and social development, rapid urbanization is also producing negative externalities, such as widening inter-regional economic gap, social welfare problems, misapplication of land use, congestions, farmland conversion, environmental degradation (Su et al., 2017).

China's central government's "New-Type Urbanization" is designed to reorient urban policies from land-centered to people-oriented urbanization (Su et al., 2017). Megaregions as part of this new-type urbanization strategy are used to promote sustainable, balanced and more dispersed development of the entire national territory. Thus, the Chinese government has taken the idea of megaregions as a normative call for action (Su et al., 2017; Harrison and Gu, 2019). While the concept was first introduced in the 11th Five-year Plan (2006–2010) as one of possible spatial patterns, in the 12th Five-Year-Plan (2011–2015), megaregions (urban agglomerations) were already mainstreamed as a cornerstone urbanization policy. Consequently, in December 2013, the Central Work Conference on Urbanization (the highest level meeting on urban issues held by the Central Committee of the Communist Party) gave megaregions the status of a main form of urbanization policies.

In March 2014, the State Council of China launched its National New Urbanization Planning (2014–2020), which emphasizes the strategic importance of megaregions to national economic growth, coordinated regional development and international competition. It designated 18 megaregions (CCCPC & SC, 2014; Xu, Wang, Zhou, Wang, & Liu ,2016). In November 2016, the central government announced speeding-up megaregion development and approved the establishment of 20 megaregions (Su et al., 2017). By 2019, the State Council has approved more detailed development plans for eight megaregions, and plans for the others are being drafted. However, megaregions in China emerge not so much as the 'organic' outcome of the spatial evolution of the urban systems, but as a product of a deliberate administrative and planning regime, involving multi-scalar actors.

Despite these 20 megaregions were delineated by the central government, their precise spatial configurations have not been defined. Our analysis will adopt the spatial boundaries of the 20 megaregions originally identified in Fang et al. (2015) (Figure 1). As shown in Table S1, the 20 megaregions are of high importance to China, since they collectively accounted for 64% of the total number of cities at prefecture level and above, 26% of China's land area, host 64% of China's population and 86% of its national gross domestic product (GDP) in 2014.

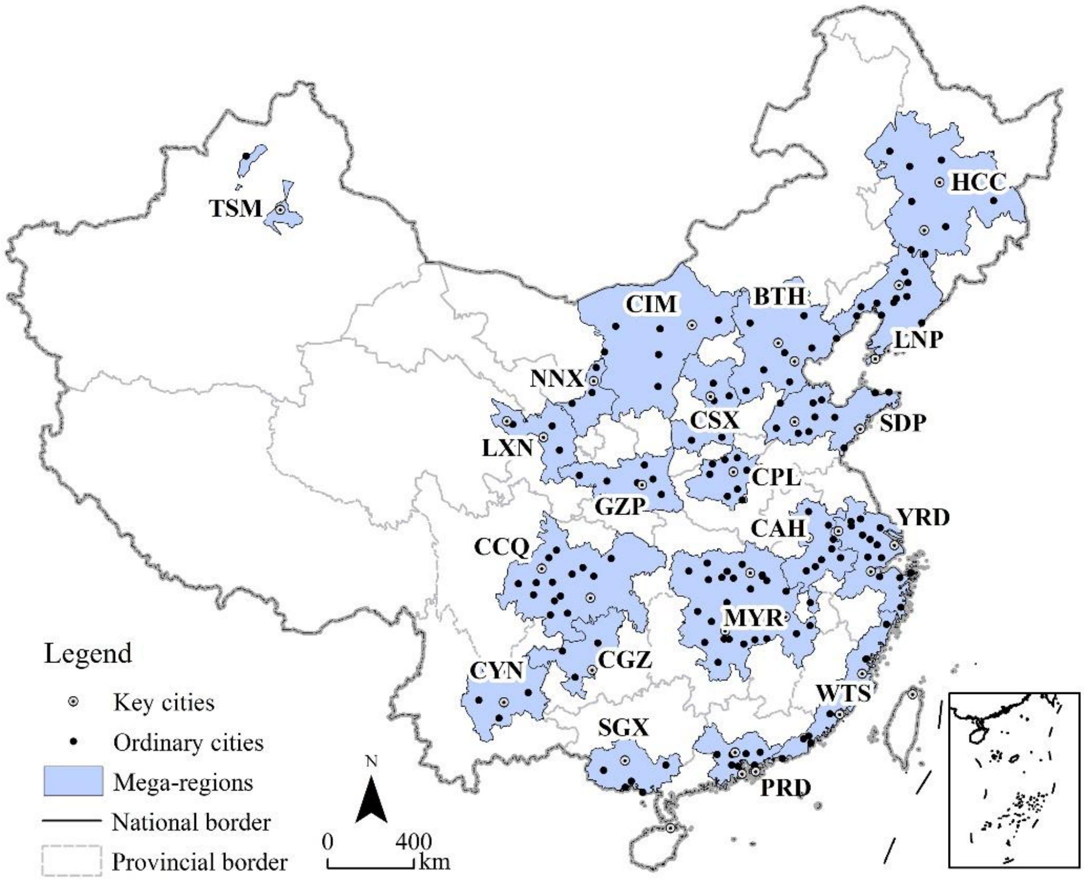

Fig. 1. The spatial configuration of the 20 megaregions in China (Fang et al., 2015)
Note: YRD=Yangtze River Delta, PRD=Pearl River Delta, BTH=Beijing–Tianjin–Hebei, MYR=Middle Yangtze River, CCQ=Chengdu=Chongqing, LNP=Liaoning Peninsula, SDP=Shandong Peninsula, WTS=Western Taiwan Straits, HCC=Harbin–Changchun, CPL=Central Plain, CAH=Central Anhui, GZP=Guanzhong Plain, SGX=Southern Guangxi, TSM=Tianshan Mountains, CSX=Central Shanxi, CIM=Central Inner Mongolia, CYN=Central Yunnan, CGZ=Central Guizhou, LXN=Lanzhou–Xining, NNX=Northern Ningxia.

2.3 Measuring the polycentricity of megaregions

The planning practices of polycentric megaregions are not uncontroversial. Megaregions are not formally recognized in the hierarchy of administration structure contrary to cities and provinces. Planning in cross-jurisdictional megaregions can be susceptible to varying levels of regulations and negotiations, in which historical and cultural linkages, and (political) power relations need to be taken in consideration. This unsurprisingly makes plans for the development of megaregions complex.

Socioeconomic variables such as population, employment, economic output, built-up areas and nighttime light data are widely employed to estimate the (morphological) polycentricity of megaregions (Wang & Duan, 2018; Wei, Taubenbock, & Blaschke, 2017; Wen & Thill, 2016; Taubenbock, Standfus, Wurm, Krehl, & Siedentop, 2017). The conventional approach, which is based on the 'characteristics' or 'attributes' of cities, has emphasized the effects of individual member regions but ignored inter-regional linkages within city networks (Liu, Derudder, & Wu, 2016). However, a shift towards a network thinking has stressed the importance of cities' positions within the inter-city flows of people, information and goods (Meijers, 2005; Liu, Derudder, & Wu, 2016). Consequently, various intercity relational data have been used to examine the functional polycentricity, including transportation connections (Liu et al., 2016), firm connections (Zhang & Kloosterman, 2016), social media connections (Cai, Huang, & Song, 2017) or knowledge connections (Chen et al., 2015; Li & Phelps, 2017). Despite this, the majority of empirical studies are confined to a handful of the most developed megaregions, such as Yangtze River Delta and Pearl River Delta (Li & Phelps, 2017; Zhao, Derudder, & Huang, 2017), but the extent to which China's planned megaregions are polycentric or not and which of them are polycentric or not remain largely unexplored. Exceptions include the works by Liu and his colleagues who used intercity transportation networks and fine-grained population data for examining morphological and functional polycentricity in all urban regions in China (Liu, Derudder, & Wang, 2018; Liu, Derudder, & Wu, 2016). In what follows, we build on their work but develop a different methodology and use a different data set. Our study establishes a unified analytical framework to comprehensively measure, classify, visualize and identify polycentric development of all the 20 megaregions in China.

3. Methods and data

3.1 Combining functional and morphological polycentricity

Since there is no consensus in literature on how to gauge polycentricity, this paper develops an integrated analytical framework to measure functional and morphological polycentricity of China's megaregions (see Fig. 2).

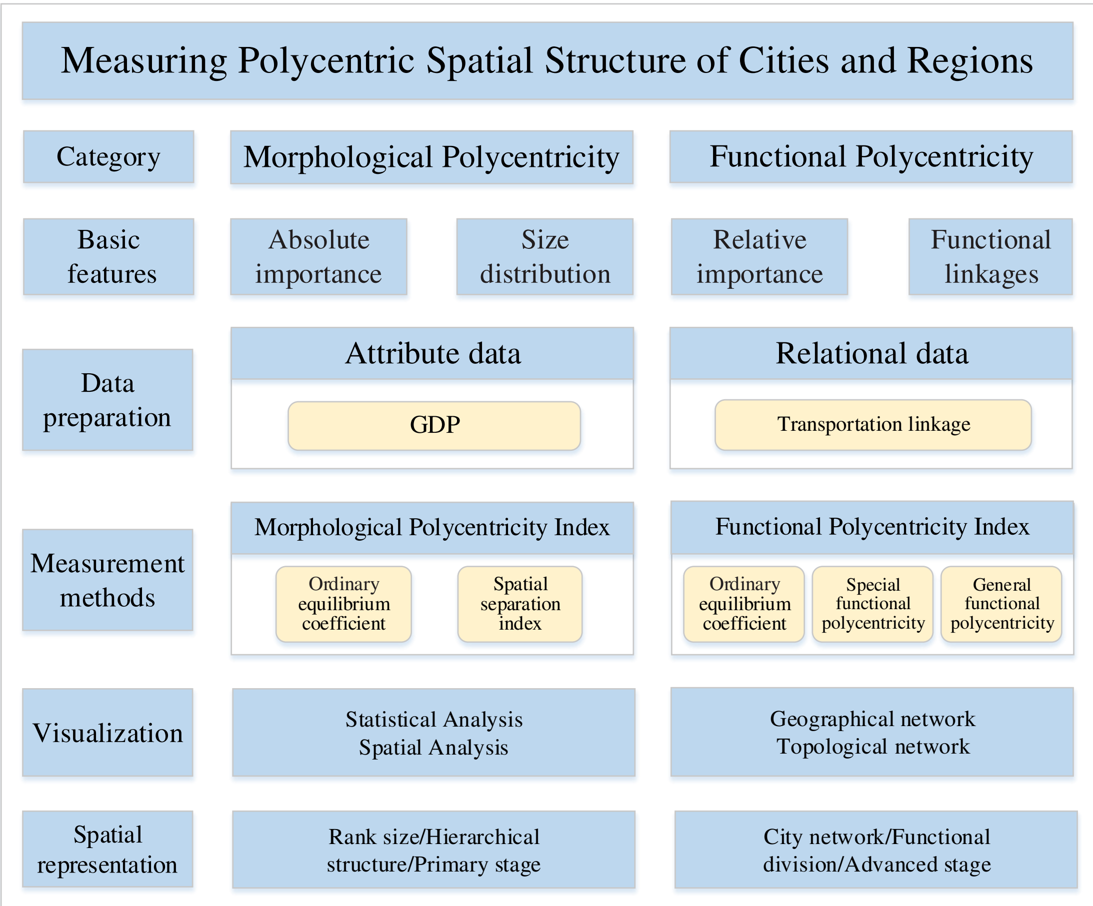

Fig. 2. The analytical framework for detecting polycentricity of megaregions

As discussed above, the morphological approach emphasizes the balance in the size distribution or absolute importance of multiple nodes/centers in a given territory. Thus, it includes two main tendencies: (1) centers should be equally weighted with respect to their size in a specific region; (2) centers in a region should have certain geographical distances between each other. As a consequence, we employ the Ordinary Equilibrium Coefficient (OEC) to determine the individual distribution of centers, and the Spatial Separation Index (SSI) to consider spatial inequality of individual centers. Then OEC and SSI are combined to generate an integrated Morphological Polycentricity Index (MPI). The 'weights' of urban centers can be calculated using attribute data (e.g. GDP, population, employment, etc).

The functional approach pays a greater attention to the distribution of functional linkages. Following Green's (2007) formal measurement of functional polycentricity, we firstly combine the Ordinary Equilibrium Coefficient (OEC) with network density to calculate Special Functional Polycentricity, and then integrate Special Functional Polycentricity of different functional networks to generate the mean polycentricity, or General Functional Polycentricity; we finally take the complementarity modifier into consideration to produce the formal Functional Polycentricity Index (FPI).

With regard to the data used in calculations, the morphological polycentricity can be measured by attribute data, while functional polycentricity by relational data. In our study, the attribute data of the social and economic development of individual cities in megaregions were obtained from the China City Statistical Yearbook 2015 as well as statistical yearbooks of the corresponding provinces and municipalities. We adopt the GDP indicator to represent the economic 'weight' of individual cities and to calculate morphological polycentricity.

As for relational data, in existing studies on polycentricity, transportation flows have been wildly used to gauge polycentricity (De Goei et al, 2010) because transportation network plays a key role in economic and social development of individual cities, and also underpins the economic and social linkages through the movement of goods and people. However, different transportation modes have varying utility as a proxy for polycentricity. For example, air traffic flows represent longer distances that are not suitable for analyzing spatial connections at the megaregional scale. Rail transport is an important way of passenger flows in China, but it is influenced by the national railway development strategy rather than megaregion governance per se. For example, some high-speed rail (HSR) lines are still in a planning or construction stages and thus many cities are disconnected from the HSR networks within megaregions.

What appears to be more useful in the analysis of intercity functional relationship at the mega-regional scale is road passenger transportation. It is universal and has a relative stability and homogeneity. Road passenger traffic mainly takes short distance, with significant spatial dependence and distance decay. We chose the daily intercity bus schedules representing road passenger flows as the key indicator to gauge the intercity functional relationships at a megaregional scale. Daily intercity bus schedules were mainly collected from China's largest bus schedule online search engine, checi.cn. The bus schedules between city pairs were taken from multiple sources (bus.ctrip.com, changtu.com and bus365.com) and cross-checked to ensure their completeness and accuracy. Finally, through the data clearing and reconstruction, the intercity symmetrical matrixes were aggregated.

As a further step from measuring MPI and FPI, we then used a visualization technology to illustrate the development of the polycentric spatial structures of cities and regions. A spatial analysis is used to demonstrate the geographies of morphological polycentricity and a network analysis is applied to display the geographies of functional polycentricity, including through the use of heatmaps and chord diagrams. We employed an R package to draw heatmaps for demonstrating functional polycentricity of megaregions. In the heatmaps, the color of each grid denotes the total number of functional linkages between two cities; the cities listed in the two symmetrical coordinates are rearranged by cluster analyses so that they can reveal the internal structures of the city networks. At last, we could further explain spatial representation of polycentricity development of megaregions by utilizing the key indicators from morphological and functional dimensions respectively.

3.2 Morphological Polycentricity Index (MPI)

The MPI was calculated in the following steps. Firstly, we use the standard deviation of spatial units in a region (Green, 2007) to describe the equilibrium distribution of centers within a region by attribute data; we define it as "Ordinary Equilibrium Coefficient":

$$OEC = 1 - \frac{\sigma_{obs}}{\sigma_{max}} \quad (1)$$

where, *OEC* is the Ordinary Equilibrium Coefficient of a megaregion, ranging from 0 (absence of equilibrium) to 1 (total equilibrium); σ_{obs} is the standard deviation of centrality of each city in a region; and σ_{max} is the standard deviation of centrality in a two-node network where one node has zero total centrality and the other has the maximum observed value. We use GDP metrics as the proxy of the economic "weight" of individual city in calculating morphological polycentricity.

To understand the morphological polycentricity, we also take into account the spatial distribution of megaregions. We extend the spatial separation index originally proposed by Midelfart-Knarvik et al. (2002). This index is calculated as follows (Pereira et al., 2013):

$$V = S' \times D \times S \quad (2)$$

where, *V* is the Venables Index of a megaregion; *S is* a column vector of S_i; and *D* is a distance matrix whose entry d_{ij} is the distance between the centroids of areas *i* and *j*; S' is the transposed matrix of *S*.

Then, the Spatial Separation Index (SSI) can be normalized by the theoretical maximum V_{max} as follows:

$$SSI = \frac{V}{V_{max}} \quad (3)$$

where, *SSI* represents the Spatial Separation Index of a megaregion; V_{max} is the maximum attainable value of spatial separation index that can be calculated when all values have an absolutely homogeneous distribution along the edge of a region. If *SSI* = 1, centers within a region are as much spatially separated as possible.

Finally, our proposed Morphological Polycentricity Index (MPI) can be integrated by:

$$MPI = OEC \times SSI \quad (4)$$

3.3 Functional Polycentricity Index (FPI)

Similar to morphological polycentricity, functional polycentricity stresses the distribution of significant cities within a region, but focuses on functional linkages between individual centers through flows and networks. Thus, functional polycentricity is measured more from a network perspective.

In the previous part, OEC has been introduced to assess the relative balance of city centralities in a region. Here, we also use OEC to calculate the equilibrium distribution of spatial units but using relational data:

$$OEC = 1 - \frac{\sigma_{obs}}{\sigma_{max}} \quad (5)$$

where, OEC represents the Ordinary Equilibrium Coefficient of a megaregion, ranging from 0 (absolute absence of equilibrium) to 1 (total equilibrium); σ_{obs} represents the standard deviation of total centrality (e.g., indegree or outdegree) of each city in a region; and σ_{max} is the standard deviation of total centrality (e.g. indegree or outdegree) in a two-node network where one node has zero total centrality and the other has the maximum observed value. The indegree and outdegree of centrality of individual city can be separately calculated from intercity in-commuting and out-commuting flows.

One region with functional polycentricity means cities within the region must be functionally linked to one another and form dense connections between each other. Thus, network density is a key indicator for functional polycentricity. The network density of the graph Δ can be calculated:

$$\Delta = \frac{L}{L_{max}} \quad (6)$$

where, Δ represents the network density; L is the total actual connections within a region; and L_{max} is the theoretical maximum value of total connections. L_{max} is not always easy to derive and we here use the total population of each region to evaluate the maximum connections of the corresponding region.

Then the Special Functional Polycentricity is defined for a single function as follows:

$$P_{SF}(N) = OEC \times \Delta \quad (7)$$

where, P_{SF} is the Special Functional Polycentricity for a function F within network N; OEC is the Ordinary Equilibrium Coefficient of network N; Δ is the network density of network N that functional polycentricity falls to zero when there is no linkage flow between cities.

Based on the Special Functional Polycentricity, General Functional Polycentricity is used to describe the mean polycentricity across a variety of functions within the same geographical area that combines several values of Special Functional Polycentricity into a single figure:

$$P_{GF} = \sum_{n=1}^{n} P_{SF}\,(N_1, N_2, \ldots N_n)/n \quad (8)$$

where, $P_{GF}(N_1, N_2, \ldots N_n)$ is general functional polycentricity for functional networks N_1, N_2, … N_n; $P_{SF}(N_1, N_2, \ldots N_n)$ are values of Special Functional Polycentricity for networks N_1, N_2, …N_n; and n is the number of networks. In this paper, functions of in-commuting and out-commuting were combined to generate the mean polycentricity.

However, functionally monocentric networks may complement one another creating a functionally polycentric system when put together. To this end, a complementarity modifier is taken into consideration:

$$\varphi = 1 - \sigma_{P(F,N_1,\ldots N_n)} \quad (9)$$

where, φ is a complementarity modifier; $\sigma_{P(F,N_1,\ldots N_n)}$ is the standard deviation of values for Ordinary Equilibrium Coefficient, $P(F, N_1, \ldots N_n)$ for functional networks $(N_1, \ldots N_n)$.

After all the steps above, the Functional Polycentricity Index (FPI) that can incorporate multiple functional networks can be formally defined as:

$$FPI = P_{GF} \times \varphi \quad (10)$$

4. The polycentricity of China's megaregions

4.1 Five types of megaregions

Table S1 presents the morphological and functional polycentricity indexes of China's 20 megaregions. Overall, our results show divergence between morphological and functional dimensions, while the functional polycentricity varies more strongly than morphological polycentricity. From the morphological view, the megaregions of Shandong Peninsula (SDP), Yangtze River Delta (YRD), Middle Yangtze River (MYR), and Chengdu-Chongqing (CCQ) fall into the first class in MPI (> 0.46), in contrast, the Beijing–Tianjin–Hebei (BTH), Pearl River Delta (PRD), and Central Plain (CPL) megaregions demonstrate the lowest levels of morphological polycentricity (with the smallest value of 0.26). However, from the functional perspective, PRD is most polycentric in comparison with other megaregions; SDP and YRD also exhibit a high degree of functional polycentricity, closely following PRD. Meanwhile, no significant correlation exists between morphological and functional polycentricity. This indicates a certain spatial mismatch between the morphological and functional polycentricity of megaregions. In other words, a megaregion with a high degree of morphological polycentricity does not necessarily reveal a similar degree of functional polycentricity, and vice versa.

Using a two-dimensional quadrant method, a typology was derived based on the degree of functional and morphological polycentricity. The method was employed by Liu and their colleagues (Liu, Derudder, & Wang, 2018; Liu, Derudder, & Wu, 2016). Individual megaregions are plotted with their scores of morphological and functional polycentricity as coordinate. By centering on the point with mean values of morphological and functional polycentricity, 20 megaregions were divided into five quadrants as shown in Fig. 3. In addition, the megaregions' GDP and population size are provided as background information, which helps better understand the variations among megaregions. The size of circles corresponds to megaregions' GDP. The color of circles represents the megaregions' population.

The five quadrants respectively represent the megaregions with: (i) morphological polycentricity-functional polycentricity (2 in total), (ii) morphological monocentricity-functional polycentricity (1 in total), (iii) morphological-functional monocentricity (8 in total), (iv) morphological polycentricity-functional monocentricity (4 in total), and (v) generalized dispersion (5 in total). In general, most of the megaregions represent functional monocentricity while megaregions are more dispersed in the morphological category.

Below we analyze the spatial characteristics of each of these types of megaregions through a spatial visualization technology, based on geographic network and heatmap. The geographic network will portray the spatial distribution of city clusters and the heatmap will provide the topological structure between cities within megaregions.

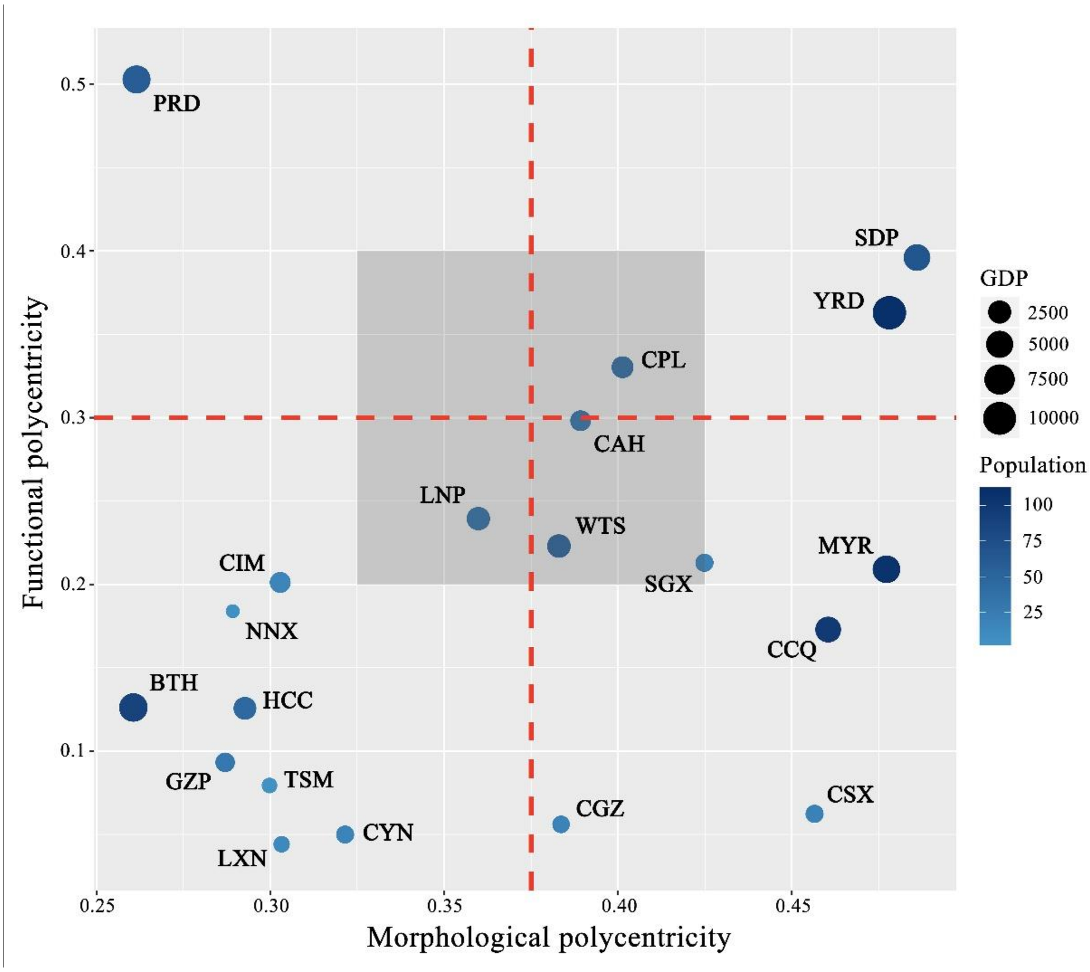

Fig. 3. A typology of China's megaregions in terms of functional and morphological polycentricity

4.2 Upper right quadrant: Morphological polycentricity-functional polycentricity

The position in this quadrant indicates a balanced relation between size distribution and functional network in the megaregion. Megaregions with a polycentric morphological and functional model encompass several mutually complimentary central cities as economic drivers and are characterized by well-developed and dense infrastructural networks.

Here, the Shandong Peninsula (SDP) and Yangtze River Delta (YRD) megaregions demonstrate the spatial patterns of decentralized concentration in both morphological and functional dimensions. Figure S1 provides a more detailed visual presentation of the polycentricity in these megaregions. Note that in Figure S1 the network graph on the left represents the spatial distribution of intercity linkages, while the heatmap represents the topological structure of intercity linkages within megaregions.

The SDP megaregion encompasses 13 cities within the Shandong peninsula and displays a rapid development. The economic cores are its provincial capital city (Jinan), one vice-provincial level city (Qingdao), and a coastal city (Yantai), with other smaller cities also having relatively large population and economy size. Qingdao and Yantai are two of the fourteen coastal cities opened to foreign direct investment in 1984. From the spatial morphology, there emerges a polycentric spatial pattern with multiple hubs and dense interconnected linkages.

The YRD megaregion has been generally considered as one of the most developed and economically competitive megaregions. The 16 cities in the whole region have relatively low intercity inequality in social and economic terms, and the industrial division and cooperation between cities has been established and deepened over many decades. This megaregion are anchored by a global metropolis (Shanghai) and two provincial cities (Nanjing and Hangzhou), and also includes two middle-size cities with strong economic performance (Suzhou and Ningbo) – which only facilitates the processes of regional integration.

4.3 Upper left quadrant: Morphological monocentricity-functional polycentricity

The balanced distribution of linkages and flows resulting from economic complementarities between different centers is an essential characteristic with regard to functionally polycentric regions. However, a functionally polycentric region is not necessarily morphologically polycentric. There is only one megaregion that demonstrates this kind of morphological monocentricity and functional polycentricity, namely the Pearl River Delta megaregion (PRD) in southern China. Since China's reforms and opening up in the early 1980s, PRD has stepped into the era of industrialization and urbanization. It has become one of the most vibrant economic regions with the highest urbanization rate compared to other megaregions.

The PRD megaregion is anchored by one provincial level city (Guangzhou) and one vice-provincial level city (Shenzhen), and also includes some prefecture-level cities which also have good economic performances (Figure S2). Shenzhen, the first city in China to experiment with market-oriented reform and opening up, is a modern and prosperous metropolis. Nevertheless, there are significant regional disparities within PRD. For example, the GDPs of Guangzhou and Shenzhen (above 1600 billion RMB) are nearly nine times higher than those of Zhuhai and Zhaoqing (less than 190 billion RMB). The distributed patterns of other socioeconomic indicators show similar trends. However, from the functional perspective, the relatively mature cooperation mechanism and functional network have been established between the nine main cities of PRD. This can be attributed to the recent deliberate intercity cooperation initiatives to promote coordinated industrial development and transport infrastructure sharing.

4.4 Lower left quadrant: Morphological-functional monocentricity

A monocentric megaregion is often centered on a single large city and thus encapsulates a core-periphery division. Megaregions with morphological and functional monocentricity are less balanced both in weight distribution and functional relations. We identify that the majority of China's megaregions fall into category, including Beijing–Tianjin–Hebei (BTH), Harbin–Changchun (HCC), Guanzhong Plain (GZP), Central Inner Mongolia (CIM), Central Yunnan (CYN), Lanzhou–Xining (LXN), Northern Ningxia (NNX), and Tianshan Mountains (TSM). Figure S3 shows the size distribution and functional networks of six of these eight megaregions with morphological and functional monocentricity (NNX and TSM are removed; they only have four and two prefecture-level cities respectively).

Generally, most of the megaregions in this quadrant have a high-level urban primacy ratio and show a significant uneven development. The BTH megaregion, anchored in Beijing and Tianjin, has a tremendous population and economic size while the industrial division and cooperation system has not been formed, because Beijing is absolutely dominant in this urban agglomeration. Since the social and economic inequality between cities in Beijing, Tianjin, and Hebei provinces has been widened, the central government implements a national project for the Beijing-Tianjin-Hebei collaborative development. The HCC megaregion is centered on two provincial capital cities (Harbin and Changchun). The megaregions of GZP and CYN are typical monocentric spatial structures, respectively centered on their provincial capital cities (Xi'an and Kunming). Similar to HCC megaregion, LXN megaregion is anchored by Lanzhou (the capital city of Gansu province) and Xining (the capital city of Ningxia Autonomous Region).

4.5 Lower right quadrant: Morphological polycentricity-functional monocentricity

This quadrant is morphologically polycentric but functionally monocentric. One megaregion in Central China (Middle Yangtze River) and three megaregion in Western China (Chengdu-Chongqing, Central Shanxi and Central Guizhou) fall in this category (Figure S4). Middle Yangtze River megaregion (MYR) is the one of largest constellations of cities, stretching over the total area of over 283,000 square kilometers, comprising of 28 prefecture-level cities located in the Hubei, Hunan and Jiangxi provinces. From the morphological perspective, three quasi-independent urban clusters can be identified within MYR, centered on the three provincial capital cities (Wuhan, Changsha and Nanchang). Although there are substantial functional linkages between cities within each of these individual urban clusters, few linkages exist between them. Central Shanxi megaregion (CCQ) is the most important in western China. The urban networks of CCQ concentrate on the two central cities (Chengdu and Chongqing), while the other relatively small cities are less visible in the functional networks. The megaregions of Central Shanxi (CSX) and Central Guizhou (CGZ) have a relatively small number of cities and the functional linkages are less balanced.

4.6 The near-core: Generalized dispersion

Five megaregions can be classified into the "moderate" category of generalized dispersion, demonstrating a "middle-way" in their spatial patterns, with no significant spatial clustering. Central Plain (CPL), Central Anhui (CAH), Liaoning Peninsula (LNP), Western Taiwan Straits (WTS) and Southern Guangxi (SGX) all fall into this category (Figure S5). These megaregions are in an intermediate state of their spatial formation, which is not a monocentric structure, but nor is it strongly polycentric. Within these regions, there is no significant economic core to dominate the whole region, while the socio-economic activities and linkages demonstrate a relatively balanced distribution. The spatial evolution of these megaregions appears to be open-ended and dependent on individual cities in the development of future urban networks.

5. Discussion and conclusions

As the pivotal phenomena in the ongoing globalization and localization, megaregions are just one of many competing spatial imaginaries; however, they have undoubtedly attracted considerable attentions in both academic and policy literature. Megaregions have taken a particularly policy-prominent role in China. The first Central Work Conference on Urbanization and the National New-type Urbanization Plan (2014–2020) defined megaregions as the main entities in driving national urbanization. Chinese government sees megaregions as a regional policy mechanism designed to promote spatial competition, polycentricity and spatial cohesion.

Our study has put the spatial structures of megaregion governance under further scrutiny. We demonstrate that there is a divergence between the morphological and functional dimensions. This indicates a certain spatial mismatch between the morphological and functional development of megaregions. It is particularly important that the majority of megaregions perform quite badly with respect to their functional polycentricity. Only a few megaregions are functionally polycentric, while eight megaregions are both morphologically and functionally monocentric (including the Beijing–Tianjin–Hebei megaregion). Most functionally polycentric are Pearl River Delta, Shandong Peninsula, and Yangtze River Delta.

The absence of a strong inter-city network within some megaregions raises three important policy-relevant questions: (a) whether these administratively delineated megaregions are actually 'megaregions' as originally conveyed by this very concept or whether they are simply constellations of loosely connected individual urban systems framed politically as 'megaregions'; (b) whether the spatial dimensions of the so-called megaregions in China have appropriately reflected their internal structure, functioning and operation; and (c) whether China genuinely wants to build these delineated megaregions as polycentric spatial systems for their sustainable and internally balanced spatial development or whether the motives are rather the reproduction of the more narrow competitive high-growth agenda via new spatial configurations.

We do realize that in the context of China's government-directed urbanization these are rather chicken-or-egg questions, since the actual 'content' and development of megaregions may well follow their formal identification as governable and plannable subjects. If so, our study demonstrates that if China wants to achieve some greater levels of polycentricity and spatial cohesion in application to its megaregions as they are currently delineated by policy, differentiated policies should be implemented for the development of different megaregions. This suggests that the governments should consider measures to coordinate megaregions' functional orientation, factor mobility and resource sharing, and to promote cooperation mechanisms. More cities should be encouraged to participate in the production networks and value chains, and then establish interconnected urban networks between multi-scalar regional spaces. In this way, megaregions can emerge a more genuine driver for spatial polycentricity.

Furthermore, polycentricity can emerge differently at different spatial scales. Indeed, some megaregions do already contain functionally polycentric sub-systems, but do not perform as a polycentric structure at the scale of the whole megaregion. A more nuanced attribution (or non-attribution) of different urban systems to particular megaregions might help adjust spatial development policies to the functional specificities of these territories and optimize their internal structures and development opportunities.

Therefore, future research should pay more attention to the formation mechanism of megaregional process and differentiated policies for the development of different megaregions in China. Having said that, the broader question is whether 'polycentricity' and 'megaregions' need to be at all seen as a kind of panacea or preoccupation for urban and regional development policy. What is really important for policy-makers and planners is to avoid thinking 'technocratic fixes' along some (new or old) spatial development imaginaries and rather to focus on providing genuinely enabling conditions for all people and places to fully realize their potentials and aspirations.

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Supplementary Materials

Table S1

Socio-economic indicators and polycentricity indexes of megaregions in China, 2014

Megaregion	Abbreviation	Major cities	Number of cities	Area	Population	GDP	MPI	FPI
Yangtze River Delta	YRD	Shanghai, Nanjing, Hangzhou	16	112.6	110.2	10,602	0.48	0.36
Pearl River Delta	PRD	Guangzhou, Shenzhen	9	54.9	57.6	5,765	0.26	0.50
Beijing–Tianjin–Hebei	BTH	Beijing, Tianjin	10	181.7	88.3	6,069	0.26	0.13
Middle Yangtze River	MYR	Wuhan, Changsha, Nanchang	28	283.0	110.0	5,591	0.48	0.21
Chengdu-Chongqing	CCQ	Chengdu, Chongqing	16	239.5	97.5	4,067	0.46	0.17
Liaoning Peninsula	LNP	Shenyang, Dalian	12	117.2	37.1	2,743	0.36	0.24
Shandong Peninsula	SDP	Jinan, Qingdao	13	113.6	67.2	4,819	0.49	0.40
Western Taiwan Straits	WTS	Fuzhou, Xiamen	11	78.8	53.7	2,811	0.38	0.22
Harbin–Changchun	HCC	Harbin, Changchun	10	279.1	45.4	2,430	0.29	0.13
Central Plain	CPL	Zhengzhou	9	59.2	42.4	2,046	0.40	0.33
Central Anhui	CAH	Hefei	10	80.8	33.3	1,562	0.39	0.30
Guanzhong Plain	GZP	Xi’an	7	89.0	29.2	1,206	0.29	0.09
Southern Guangxi	SGX	Nanning	6	62.9	20.3	744	0.43	0.21
Tianshan Mountains	TSM	Urumqi	2	23.5	3.9	331	0.23	0.08
Central Shanxi	CSX	Taiyuan	6	87.3	20.0	742	0.46	0.06
Central Inner Mongolia	CIM	Hohhot	7	296.4	15.6	1,579	0.30	0.20
Central Yunnan	CYN	Kunming	4	94.2	17.7	715	0.32	0.05
Central Guizhou	CGZ	Guiyang	4	74.9	19.6	616	0.38	0.06
Lanzhou–Xining	LXN	Lanzhou, Xining	5	74.3	11.9	417	0.30	0.04
Northern Ningxia	NNX	Yinchuan	4	52.9	5.4	254	0.29	0.18

Note: Number of cities is the number of prefecture level cities or above within megaregions; Area in thousands of km^2; Population in millions of people; GDP in billions of RMB. MPI and FPI are respectively the morphological polycentricity index and functional polycentricity index of individual megaregions (as discussed in the text).

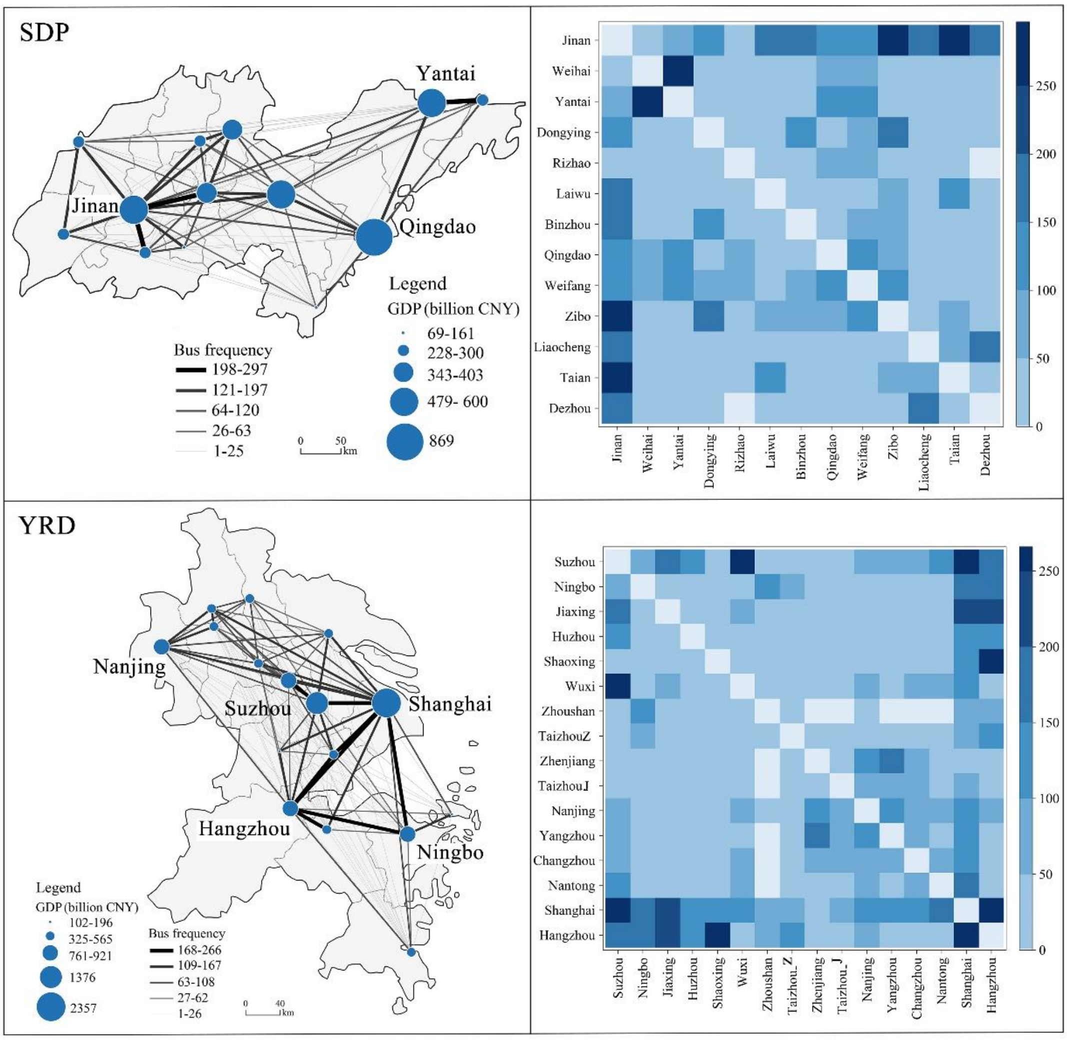

Figure S1 The size distribution and functional networks of megaregions with morphological-functional polycentricity

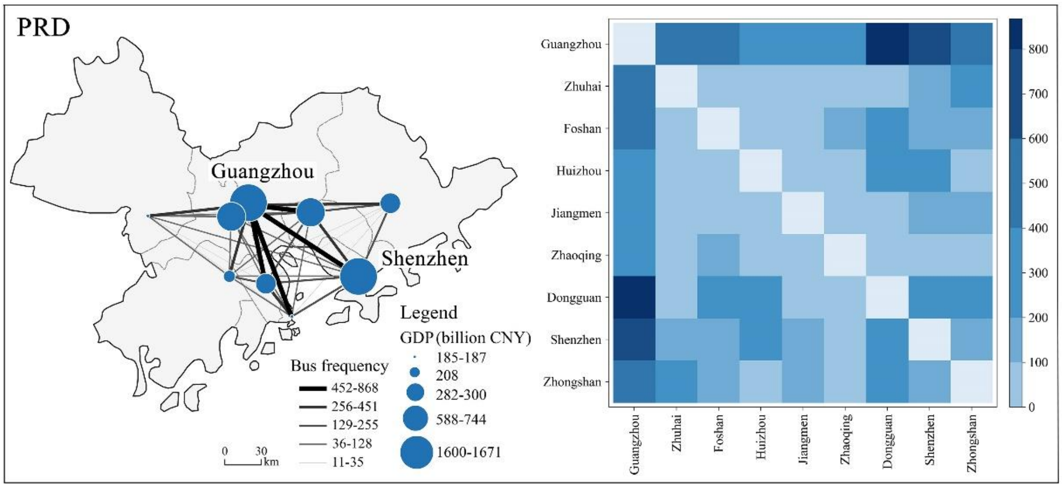

Figure S2 The size distribution and functional networks of megaregions with morphological monocentricity-functional polycentricity

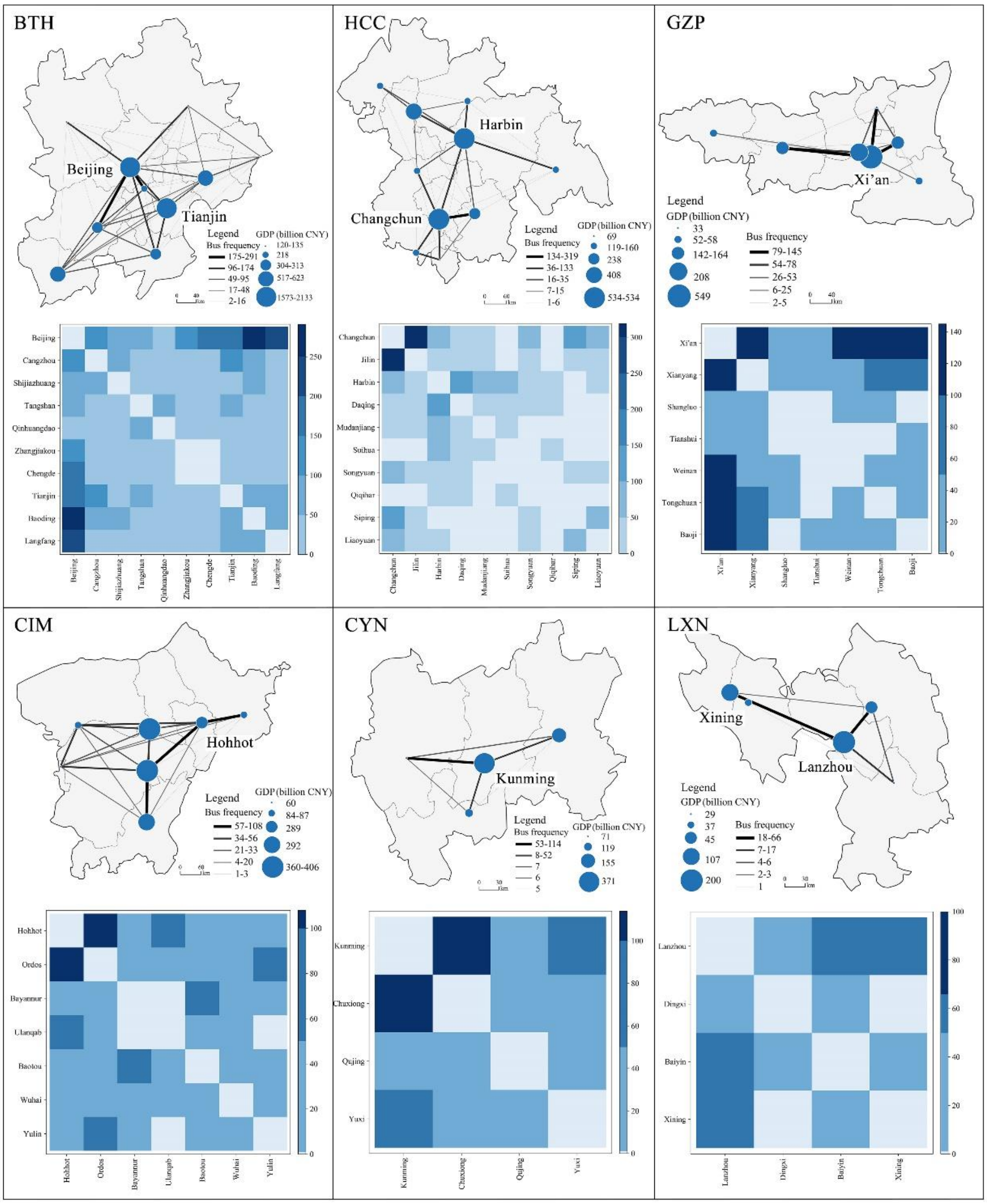

Figure S3 The size distribution and functional networks of megaregions with morphological - functional monocentricity

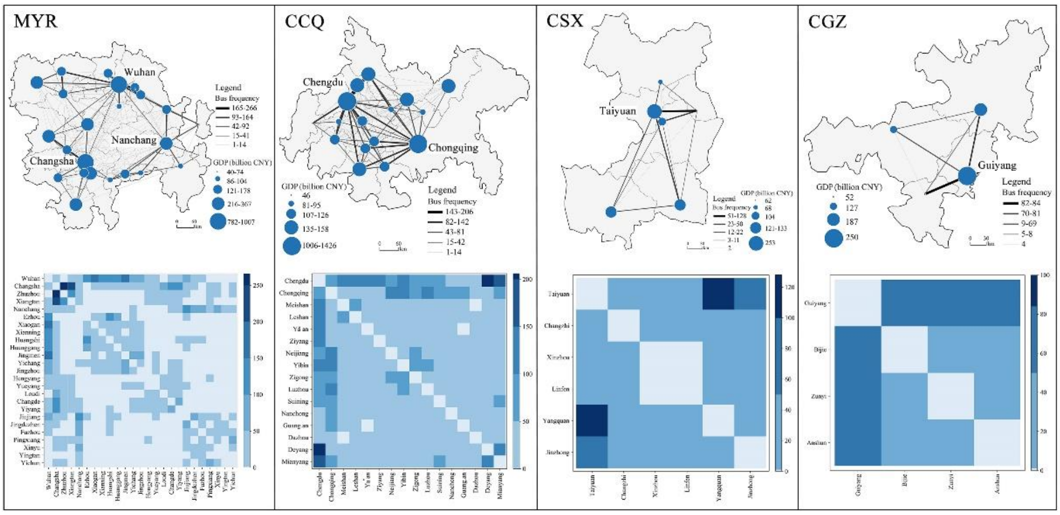

Figure S4 The size distribution and functional networks of megaregions with morphological polycentricity - functional monocentricity

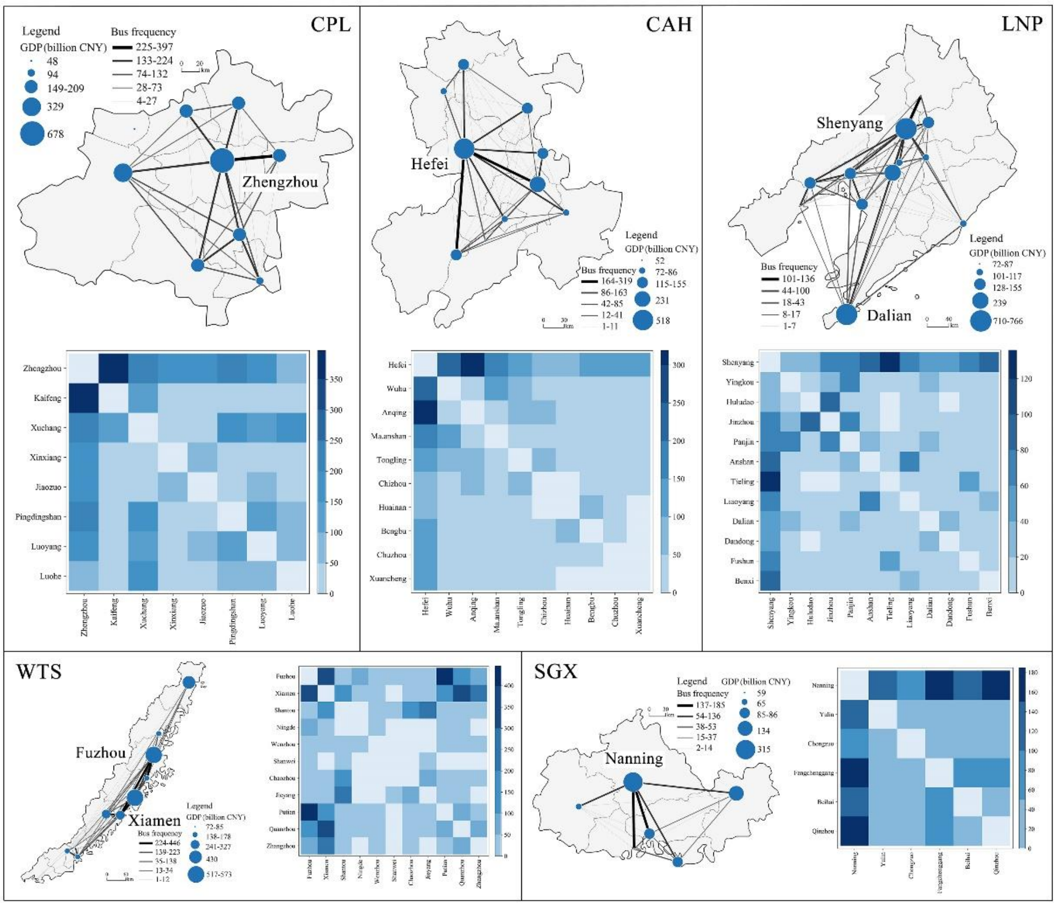

Figure S5 The size distribution and functional networks of megaregions with generalized dispersion