Spatial structure of central cities and economic performance of metropolitan areas at the urban regional scale: evidence from Hangzhou metropolitan area in China

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Abstract. Exposing the spatial structure of central cities and its effect on economic performance is crucial for promoting the sustainable development of urban regions in light of the continuous expansion of metropolitan areas around the globe. However, few empirical studies have examined how changes in the spatial structure of central cities influence the economic performance of metropolitan areas. Using panel data for the metropolitan area of Hangzhou from 2005 to 2020, this paper examines the alteration of the spatial structure of central cities contributes positively to the improvement of the economic performance of metropolitan areas, demonstrates that geographical spatial distance and urban economic scale will have a regulating effect on the economic performance of metropolitan areas. Consequently, it is necessary to promote the optimization of the multi-center city network pattern at the scale of the central city and the metropolitan area (district) where it is located, to pay attention to the coordinated development of regional polycentric spatial structure in morphological and functional dimension, which can more effectively improve regional economic performance and development, and aid in the development of a high-quality regional economy.

Keywords: metropolitan area; central cities; economic performance; spatial structure; regional economic

1 Introduction

Urban regionalization, exemplified by urban agglomerations and metropolitan areas, has become a widespread development trend[1]. As the fundamental geographical unit

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of urban agglomeration, the metropolitan area is the multi-level regional spatial organization formed by the central city as its core and the aggregation of surrounding cities[2]. It has become an increasingly significant indicator of the region's economic development. Governments globally have published a series of policies and documents to establish and expand metropolitan areas to achieve regional economic growth and sustainable development, such as the European Union (2007), Australia (2016), and China (2019). The economic performance of metropolitan areas reflects the rationality of the existing metropolitan area planning through the evaluation of the metropolitan area's resource utilization efficiency, thereby promoting the benign and stable development of the economy. Consequently, measuring and analyzing the economic performance of metropolitan areas is crucial for the planning practice of global metropolitan areas and the sustainable growth of the global economy.

The impact of changes in the spatial structure of the central city on the economic performance of metropolitan areas deserves further study. Spatial structure is the result of continuous agglomeration and interaction of economic and other social factors within a certain range. In the process of regional development, regional spatial structure and economic performance will continue to influence and interact with each other[3]. Currently, the spatial structure of central cities in metropolitan areas around the world is undergoing constant reconstruction, shifting from a traditional spatial structure to a polycentric spatial structure, London, Chicago, Tokyo, Shanghai, and Hangzhou, for instance, have transitioned from a monocentric structure to a polycentric structure with 6, 6, 7, 5, and 3 centers, respectively. Considering the important position of the central city in the process of improving the economic performance of metropolitan areas, only when the spatial structure of central cities is included in the discussion of the economic performance of metropolitan areas can a more effective economic development strategy of metropolitan areas be formulated.

The measurement of spatial structure can be roughly divided into two aspects: monocentric and polycentric. Both aspects can distinguish and measure spatial structure from the perspectives of morphology and function[4]. Specifically, morphological polycentric spatial structure indicates that elements, such as population, are distributed relatively uniformly, forming multiple roughly equal centers; functional polycentric spatial structure indicates that there is little difference in the strength of functional connections among centers in a region, and there is no obvious primary or secondary[5,6]. Under the polycentric spatial structure, the resource elements of urban agglomerations are more evenly distributed, and surrounding cities are more likely to benefit from the central cities' technology diffusion and factor diversion[7]. Moreover, the polycentric spatial structure has a positive impact on human capital accumulation, industrial agglomeration and innovation, the suppression of excessively high land prices, and FDI spillovers in urban agglomerations[8,9,10]. Current academia believe that implementing polycentric spatial strategy is essentially about improving economic performance, but few studies have examined the relationship between spatial structure and economic performance in metropolitan areas[11,12]. The relevant research fields have yet to be perfected.

In conclusion, the author intends to expand existing research from a research perspective, analyzing the effect of changes in the spatial structure of central cities on the economic performance of metropolitan areas and the impact mechanism from the perspective of central cities.

2 Materials and methodology

2.1 Study Area

As the "golden south wing" of the Yangtze River Delta and the radiating range of the Shanghai metropolitan area, the Hangzhou metropolitan area is comprised of Hangzhou, Huzhou, Jiaxing, Shaoxing, Quzhou, and Huangshan, with Hangzhou at its core. As depicted in Figure 1.

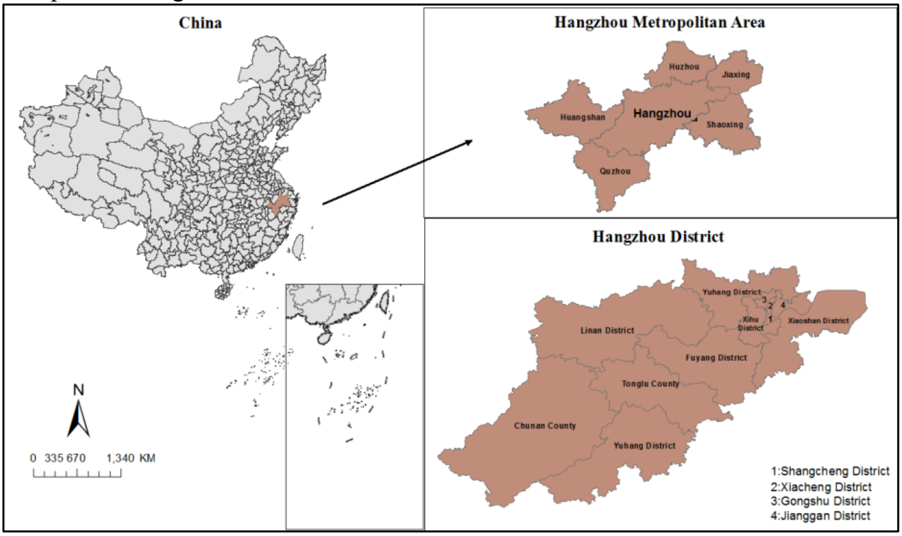

Fig. 1. Location of study area (Hangzhou, China)

Compared to other metropolitan areas in China, the Hangzhou metropolitan area is at a critical stage of metropolitan development, with great development potential, and is gradually becoming an important component of the Yangtze River Delta urban agglomeration and an international gateway to the Asia-Pacific region. As the central city of this metropolitan area, Hangzhou conforms to the general law of urban spatial structure development. After planning and development, the polycentric spatial structure of Hangzhou has gradually taken shape. Compared to other cities in the Yangtze River Delta urban agglomeration, Hangzhou is highly impacted by economic globalization and has close economic ties with other cities.

Taking the Hangzhou metropolitan area as the research object is therefore conducive to enriching the research on the relationship between spatial structure and economic performance at the urban regional scale, and is anticipated to optimize the spatial layout of urbanization in China and around the world.

2.2 Variable selection and data processing

2.2.1. Dependent variable: economic performance of metropolitan areas.

Unique to this type of urban spatial organization, the multi-layered urban structure promotes the flow of social network capital in heterogeneous spaces, thereby driving the continuous change in economic performance. In addition, land is immobile, the economic characteristics of urban space can be compared to the efficiency of utilizing land resources. Therefore, to assess urban economic performance in terms of spatial efficiency, this study employs the urban per capita output value ($GPM_{i,t}$) as an explanatory variable. The following calculation formula:

$$GPM_{i,t} = \frac{Y_{i,t}}{URM_{i,t}} \tag{1}$$

Urban economic output is known as $Y_{i,t}$. The consumer price index (CPI) of the province or region where the city is located in the calendar year is used to discount the nominal GDP to determine the city's real GDP. Among them, i represents each individual city in the metropolitan area, and t represents time.

2.2.2. Independent variable: the morphological polycentric spatial index of central cities (CCPOLYC).

Based on the measurement method of urban morphology, the morphological polycentric spatial index (CCPOLYC) is constructed, and its calculation formula is as follows.

$$CCPOLYC= \sqrt{\frac{\sum_{i=1}^{n-1}(\sqrt{d_i}\times x_i)^2}{n-1}} \tag{2}$$

where n is the total number of districts in a city, d_i is the ratio of the distance from the secondary center to the main center to the distance from the furthest secondary center to the main center in that city, and x_i is the ratio of employment in the secondary center to employment in the main center, which is expressed in the text as the ratio of the resident population in the secondary center to the resident population in the main center. By analogy, it is possible to determine the morphological polycentric spatial index of metropolitan areas（POLYC).

2.2.3. Independent variable: the functional polycentric spatial index of central cities (CCFP).

Previous studies analyzed the hierarchy, structure, and connection strength of multi-centers primarily using mathematical models, social network analysis, and other research techniques. The index was calculated using multifunctional linkages in urban areas and the correction of functional networks[13].

Firstly, the urban point function node and linear function channel are modified, and the comprehensive modified model of urban function connection is obtained:

$$GCI_{jm,t}=\frac{\sqrt{GDP_{jt}\times GDP_{kt}}}{D_{jk,t}}\times\frac{\sqrt{POP_{jt}\times POP_{kt}}}{D_{jk,t}}\times\frac{FCI_{jk,t}}{2} \tag{3}$$

where, $GCI_{jk,t}$ denotes the integrated functional linkage intensity of district j and district k in year t; GDP_{jt} and GDP_{kt} denote the year-end GDP of district j and district k in year t, respectively; POP_{jt} and POP_{kt} denote the year-end resident population size of district j and district k in year t, respectively.vWhere, $D_{jk,t} = S_{jk,t} \times T_{jk,t}/T^{`}_{jk,t}$, used to represent the modification of the urban connection by a linear function channel. Taking the administrative center of each urban district as a representative, the shortest distance in the driving mode based on the Baidu map was recorded as $S_{jk,t}$ and $T_{jk,t}$ between district j and district k in year t, the shortest spatial distance is the actual distance between district J and district k in the t year, and the time required is recorded as $T'_{jk,t}$. By correcting the point nodes in urban linkage and the relevant calculation of location quotient, the role of the market is highlighted and the market function linkage index (FCI) between urban areas is obtained as follows.

$$FCI_{jm,t} = \sum_{k=1}^{n}\left|LQ_{jk,t} - LQ_{mk,t}\right| \tag{4}$$

$$LQ_{j(m)k,t} = \frac{E_{j(m)k,t}/E_{j(m),t}}{E_{k,t}/E_t} \tag{5}$$

FCI_{jm},t denotes the market function linkage index between urban district j and urban district m in year t; $LQ_{j(m)k,t}$ denotes the location quotient of sector k of urban district j or urban district m within the central city area in year t; $E_{j\,(m)\,k,t}$ denotes the gross product of sector k of urban district j or urban district m in year t; $E_{j(m),t}$ denotes the gross product of urban district j or urban district m in year t; $E_{k,t}$ denotes the gross product of sector k within the gross product within the central city area; E_t denotes the gross product of each sector in the central city area. The $GCI_{jm,t}$, which represents the strength of intercity integrated functional linkages, is substituted into the "rank-size rule" to measure the degree of functional polycentricity of the central city. The calculation formula is :

$$\ln GCI_{jt} = C - CCFP_{jt} \times R'_{jt} \tag{6}$$

$$GCI_{jt} = \sum_{m}^{n} GCI_{jm,t}(j \neq m) \tag{7}$$

Where: n represents the total number of urban districts in the central city, GCI_{jt} represents the total number of integrated functional links between urban district j and other urban districts in the central city in year t, and R'_{jt} represents the order of the integrated functional links of urban district j in year t. After ranking, the functional polycentric spatial index of the central city $CCFP_{jt}$ in year t is obtained by the cross-sectional data regression and summing method. By analogy, it is possible to determine the functional polycentric spatial index of metropolitan areas (FP).

2.2.4. Control variables and Data processing.

The control variables in this study are as follows. The logarithm of the total fixed investment for each city over the course of various years is utilized in this study to express physical capital input (FA). The logarithm of the total employment of each city in various years is utilized in this paper to express labor force (LF). Urban quality of life was measured using Quality of Life (AME), which is the logarithm of the number of hospital beds per 10,000 persons. The level of consumption (CONSUMPTION) is expressed by the percentage of all retail sales of consumer goods in GDP; the level of opening up (FDI) is determined by the proportion of actual utilized foreign capital to GDP.

The *China City Statistical Yearbook* provided the data used in this article regarding each city's annual GDP, consumer price index, fixed asset investment, total number of employees, number of beds in healthcare facilities, degree of opening up, and level of consumption in various years.

3 Results of the Experiment and Analysis

3.1 The effect of changes in the central city's spatial structure on the economic performance of the metropolitan area

This paper begins by analyzing the effects of changes in the spatial structure of the central city on the economic performance of the metropolitan area. Models (1), (2), and (3) in Table 1 represent the models before introducing control variables, while models (4), (5), and (6) represent the models after introducing control variables.

Table 1. The impact of central city spatial structure changes on metropolitan areas' economic performance

Variable	(1)	(2)	(3)	(4)	（5）	(6)
CCPOLY	0.7230*** (0.083)		-0.326 （0.275 ）	-0.785*** (0.333)		0.070 (0.211)
CCFP		-0.372*** （0.042）	-0.540*** （0.229 ）		0.404*** （0.171）	0.440* (0.239)
EN				0.095*** (0.021)	0.095*** (0.021)	0.095*** (0.021)
FA				0.050*** (0.0140)	0.050*** (0.014)	0.050*** (0.014)
AME				0.085*** (0.028)	0.085*** (0.028)	0.085*** (0.028)
FDI				-0.164*** (0.071)	-0.164*** (0.071)	- 0.164*** (0.071)
CONSUMPTION				-0.002** (0.002)	-0.002** (0.002)	-0.002** (0.002)
_cons	0.002*** (0.012)	0.183*** （0.011）	0.265*** (0.063)	-1.409*** (0.089)	-1.605*** (0.320)	- 1.623*** (-0.182)
R^2	0.748	0.748	0.748	0.903	0.903	0.903

Note: *P<0. 10, **P<0. 05, ***P<0. 01; standard errors of estimation are in parentheses.

Only the multi-center index of the central city form is added to (1) of Table 1. According to the regression results, multiple centers in the form of the central city have a significant positive effect on the economic performance of the metropolitan area. In model (2), only the functional polycentric index of the central city is included, and the regression coefficient indicate that changes in the urban functional polycentric index of Hangzhou from 2005 to 2020 have a substantial effect on the economic performance of the metropolitan area. Negatively, it confirms that the central city's functional polycentric index can enhance the economic performance of the metropolitan area.

The possible causes are as follows: In the course of urbanization, Hangzhou has continuously incorporated land that did not originally belong to the city into its urban planning. This change in urban regional planning has given Hangzhou's spatial structure the appearance of multiple centers, but from a functional standpoint, the polycentricity is not evident, and the functional connection between the various centers still needs to be strengthened, as confirmed by the work of previous scholars.

Model (3) is based on Models (1) and (2), with the addition of the morphological polycentric index and functional polycentric index of Hangzhou City. According to the regression results, the morphological polycentric index of the central city is not statistically significant during the 2005-2020 time period that is the focus of this paper.

Models (4), (5), and (6) respectively represent the results of individual fixed effects regression for models (1), (2), and (3) after introducing control variables. Model (4) shows that the form polycentric spatial index has a certain negative impact on the improvement of the economic performance of the metropolitan area after adding the control variables. Models (5) and (6) show that, starting from two aspects of form and function, the overall changes in the urban structure of Hangzhou play a positive role in improving the economic performance of the metropolitan area. The moderating effect of functional polycentric spatial structure is more significant.

3.2 The Moderating Effects of Geographical Spatial Distance and Urban Economic Scale

The spatial aggregation of population, resources, and industries in central cities promotes financial agglomeration and economic growth. Therefore, in this section, the paper will first explore the moderating role played by spatial geographic distance in the process of changes in the spatial structure of central cities affecting the economic performance of metropolitan areas.

In the process of dividing the sample, this paper divides it into two regions according to the geographical space distance between the surrounding cities and Hangzhou, namely the short-distance region ($0 \leq S \leq 100$) and the long-distance region ($100 < S \leq 300$) . It can be seen from Table 2 below that the impact of the polycentric spatial structure of central cities on the economic performance of surrounding areas is limited by spatial distance. Within the metropolitan area, cities that are geographically and spatially closer to the central city are more significantly affected by the positive effects of changes in the spatial structure of the central city. On the one hand, cities closer to the central city can take advantage of the central city's advantage of pooling resources, while cities far away from the central city have to bear the siphoning effect. On the other hand, in the process of changes in the spatial structure of the central city, cities closer to the central city can integrate into the network space of the central city by borrowing scale, thus obtaining a positive spillover effect, while cities geographically farther away from the central city cannot benefit.

Table 2. Moderating effect of spatial geographic distance

Variable	The near region			The far region		
CCPOLY	-1.233*** (0.495)		0.274 (0.296)	0.121 (0.561)		-0.230 (0.313)
CCFP		0.634** （0.255）	0.775** （0.348）		-0.006 （0.289）	-0.181 （0.423）
EN	0.111*** （0.046）	0.111** （0.046）	0.111** （0.046）	0.044 （0.066）	0.044 （0.066）	0.044 （0.066）
FA	0.054*** （0.023）	0.054** （0.023）	0.054** （0.023）	0.031 （0.027）	0.031 （0.027）	0.031 （0.027）
AME	0.122*** （0.039）	0.122*** （0.039）	0.122*** （0.039）	0.023 （0.055）	0.023 （0.055）	0.023 （0.055）
FDI	-0.316 （0.135）	-0.032 （0.039）	-0.032 （0.135）	-0.281 （0.102）	-0.281 （0.102）	-0.281 （0.102）
CONSUMPTION	-0.001 （0.003）	-0.001 （0.003）	-0.001 （0.003）	0.002 （0.110）	0.002 （0.110）	0.002 （0.110）
R^2	0.920	0.920	0.920	0.968	0.968	0.968

Note: *P<0. 10, **P<0. 05, ***P<0. 01; standard errors of estimation are in parentheses.

Due to the fact that the size of the city itself has a significant effect on the efficiency of regional resource allocation and economic development, we will now examine whether the city's economic size has a moderating effect on the spatial structure of the central city on the economic performance of the metropolitan area.

Table 3. Moderating effect of city economic size

Variable	Smaller economic scale			Larger economic scale		
CCPOLY	-0.057 (0.061)		-0.065 (0.016)	-0.124 (0.163)		-0.080 (0.157)
CCFP		-0.022 （0.016）	-0.024 （0.016）		0.090** （0.039）	0.087** （0.039）
EN	0.032*** （0.011）	0.033*** （0.011）	0.032*** （0.061）	0.113*** （0.049）	0.173*** （0.048）	0.164*** （0.052）
FA	0.030*** （0.006）	0.025*** （0.006）	0.026*** （0.006）	0.046** （0.025）	0.036* （0.021）	0.042* （0.024）
AME	0.039*** （0.009）	0.038*** （0.008）	0.043*** （0.009）	0.047*** （0.023）	0.041* （0.021）	0.044* （0.022）
FDI	-0.219*** （0.034）	-0.222*** （0.039）	-0.219*** （0.034）	-0.196 （0.123）	-0.112 （0.117）	-0.127 （0.121）
CONSUMPTION	-0.001 （0.001）	-0.000 （0.001）	-0.001 （0.001）	0.002 （0.002）	0.000 （0.002）	0.000 （0.002）
R^2	0.937	0.939	0.940	0.934	0.942	0.942

Note: *P<0. 10, **P<0. 05, ***P<0. 01; standard errors of estimation are in parentheses.

From Table 3, we can find that the changes in the spatial structure of central cities have a more obvious positive effect on cities with larger economic scales and better economic foundations. It is hypothesized that cities with larger urban economies have the infrastructure and capacity to undertake the transfer of resources and industries from the central city, so that they can better utilize their own advantages and improve their economic performance through the external economic network of the central city.

4 Conclusions

The research results show that: (1) Overall, changes in the spatial structure of central cities play a positive role in improving the economic performance of the metropolitan area. Among them, compared with the morphological polycentric spatial structure, the functional polycentric spatial structure of central cities can promote The economic performance of the metropolitan area has improved. (2) In the process of the change of the spatial structure of the central city affecting the economic performance of the metropolitan area, the spatial geographical distance and the urban economic scale will all have a regulating effect on it.

In the process of China's new urbanization, the government should fully consider the changes in the spatial structure of the central city and the coordinated development of regions to achieve the high-quality development.

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