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Effects of Polycentricity on Economic Performance and Its Dependence on City Size: The Case of China

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Abstract: Polycentric planning strategies have often failed to achieve the expected effects. The ensuing uncertainty associated with the desirability of polycentric strategies is also reflected in the early literature which offers no clear conclusion about whether the polycentricity affects economic performance and how. This paper aims at offering a clear conclusion about it, especially its dependence on city size. Against this backdrop, we conceptualize polycentricity as a process of reclustering after decentralization to reevaluate its impact on performance. To this end, we use the city proper level Chinese Economic Census (2004, 2008, and 2013) and apply a fixed-effects panel model, the results of which show that the dependence of the urban economy on spatial structure is contingent on city size. More specifically, both decentralization and clustering (and therefore the polycentric structure) facilitate economic performance only when cities reach a certain size. We use our findings as the basis for outlining an emergent research agenda for urban polycentricity.

Keywords: polycentricity; city size; economic performance; optimal city size; China

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1. Introduction

Suburbanization or decentralization, which is fueled by the expansion of city size, has become one of the most important characteristics of urban spatial transformations worldwide. Urban planners have been seeking spatial adjustment strategies to meet the challenges caused by the agglomeration diseconomies associated with such expansion and often advocate for polycentric spatial structures. Polycentricity, they argue, is supposed to reduces the negative agglomeration effects that occur once employment is no longer centralizes in the main city center, and it facilitates cities in regaining positive momentum when employment reclusters in subcenters. However, polycentric planning practices have long been met with skepticism because they usually fail to achieve the expected effects.

Therefore, the prevailing but usually ineffective practice of polycentric planning strategy has brought about an urgent demand for research on the relationship between polycentricity and economic performance. Unfortunately, a consensus on this issue has not yet been reached (see the meta-analysis by Li et al., 2022) [1]. The reasons for this lack of consensus may stem from the following three unsolved problems. First, is the effect of spatial structure on economic performance contingent on city size, especially at the metropolitan level? Although empirical results on the total effects of polycentricity on the economy have been enriched in many countries, such as the USA [2], Korea [3], or China [4,5], sufficient attention has not been paid to the moderating effects of city size. Second, what is the underlying mechanism for the economic performance of polycentricity?

The two theoretical paths, namely decentralization [6,7] and "borrowed size" [8–10] have not been supported by empirical evidence. Third, how to deal with the effects of the reverse causality of the economic performance on polycentricity? The results achieved by cross-sectional or OLS models [2,4,11,12] are likely to be biased.

Our paper aims to expand our understanding of the effect of urban spatial structure on economic performance. In particular, we delve into its linkages with city size and whether size exerts a moderating effect on the relationship between economic performance and spatial structure at the Chinese city proper level. To provide empirical evidence for two theoretical paths of polycentricity (decentralization and "borrowed size"), this analysis unfolds polycentricity in the process of reclustering after decentralization, a process that has generally neglected in the previous empirical literature. Furthermore, we improve on commonly used cross-sectional models and historical instrumental variables by adopting a two-way fixed-effects panel model and more effective instrumental variables for a two-stage least squares (TSLS) model.

2. Literature Review and Hypotheses

2.1. Concept of Urban Spatial Structure

The concept of urban spatial structure, despite its centrality in the urban economics and regional science literature, remains ambiguous. In this paper, we focus mainly on the morphological spatial structure rather than the functional structure, which involves the networks between centers [13,14]. Moreover, we measure spatial structure with data on the distribution of employment rather than with other human activity data such as population [11], land use [15], or nighttime light [16,17]. The main reason for this choice is that our research aims at addressing the spatial frictions associated with the labor market.

However, despite the multiplicity of morphological definitions, there is considerable overlap between the key dimensions and the initial conceptualization that Anas et al. (1998) synthesized in their work [18]. They proposed that urban spatial structure can be defined along two dimensions, namely, the degree of centralization versus decentralization and the degree of clustering versus dispersion. Anas et al. (1998) thus suggested two dimensions to describe urban spatial structures, specifically, centralization and clustering [18]. Lee (2007) elaborated on and clarified Anas et al.'s (1998) conceptualization and named these dimensions centralization and concentration [19]. Centralization is the extent to which employment is concentrated near a central business district (CBD). Concentration, similar to the dimension "the degree of clustering versus dispersion," measures the extent to which employment is either clustered in a few nodes or dispersed. Thus, polycentricity is the combined result of decentralization and clustering [18,19]. Accordingly, we illustrate this process of polycentricity in Figure 1.

2.2. Relation between Economic Performance and Urban Spatial Structure

The distribution of urban employment determines the spatial organization of employment centers and how they are connected with each other. This structure, in turn, may have serious implications for urban prosperity depending on whether it benefits productivity. Polycentricity may contribute to economic performance via the following two potential mechanisms: (1) decentralization reduces the agglomeration diseconomy of the main centers [6,7]; and (2) clustering in subcenters recovers the positive externalities through "borrowed size" [8–10]. However, decentralization has the potential to harm the economy when it fails to compensate for the reduction in the agglomeration economies of the main center. Therefore, we group the existing empirical studies that examine the influence of spatial structure on economic performance into three classes: those that study the spatial dimensions of polycentricity, those that study centralization, and those that study clustering.

(1) The literature on the spatial dimensions of polycentricity tends to focus on the direct relationship between polycentricity (as measured by the balance in the distribution of city/center sizes) and urban economic performance. However, differences in oper-

ationalization have led to inconsistent results. For example, some studies identified a positive relationship between polycentricity and urban economic performance among US metropolitan areas [2] or Korea [3], while Lee and Gordon (2007) found no significant relationship [12]. The results for Chinese cities are heterogeneous across different study scales. Zhang, Sun, and Li (2017) found support for a positive association between polycentricity and economic performance within a sample of city proper areas [4]. However, Sun and Li (2016) and Li, Sun, and Zhang (2018) rebutted their argument and found contrary evidence at the municipal administrative area level [16,20]. Furthermore, Wang, Derudder, and Liu (2019) showed that intra-urban monocentricity and inter-urban polycentricity are linked with higher levels of labor productivity [5].

(2) The relationship between centralization and urban economic performance exhibits similar inconsistencies. Cervero (2001) and Veneri and Burgalassi (2011) assessed the effects of centralization and reported a positive impact of centralization on labor productivity [21,22]. However, Glaeser and Khan (2004) examined the influence of the percentage of employees within 3 miles of the CBD on urban economic performance and found that a 10% increase in decentralization led to, on average, 2.7% growth in GDP per capita [23].

(3) The literature on the relationship between clustering and urban economic performance is the only branch of the literature to provide seemingly consistent results. Fallah, Partridge and Olfert (2011) found that urban sprawl is negatively related to average labor productivity [24]. Qin and Liu (2015) obtained consistent results by using nighttime light data from a Chinese prefecture-level city to calculate the same index as Fallah, Partridge, and Olfert (2011) [24,25]. Furthermore, Liu, Chen, and Liu (2020) defined urban compactness using Landsat data and found that it was negatively correlated with urban GDP [15].

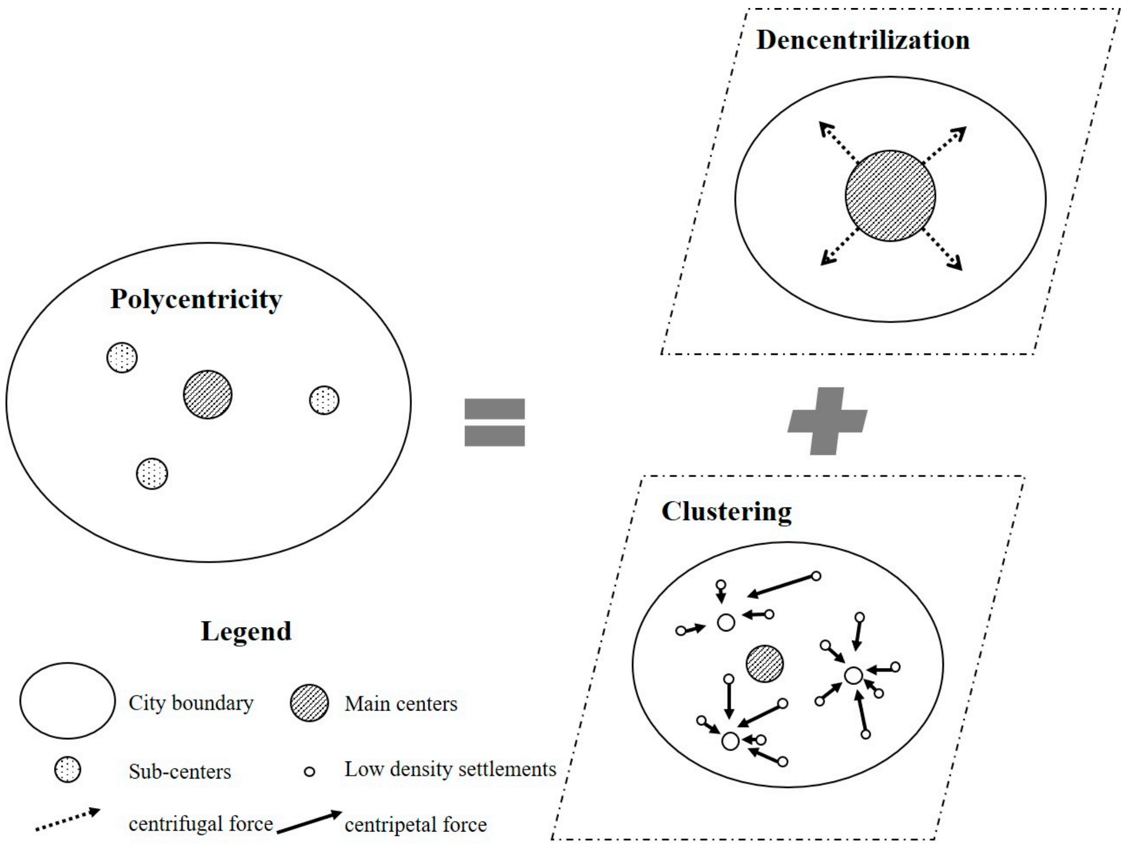

Figure 1. Two dimensions of polycentricity (decentralization and clustering).

2.3. Moderating Effect of City Size

Cities at different stages of development may have different optimal spatial structures. Our main theoretical prediction is that as cities pass a certain size threshold and continue to grow, the positive effects of polycentricity increase. This is because polycentricity tips the balance of net economic gains away from centralization and toward clustering. In other words, in large cities, as the cost of centralization increases with size and with the high concentration of activities in one location, the net benefits of clustering outside the main center overtake those of centralization.

Friedman (1966) proposed a theory of stages of spatial organization consistent with this hypothesis [26]. He expounded on a sequential process for the interaction between spatial structure and development. According to him, as economic development and city-size growth occur, the spatial structure transitions from a low-level spatial equilibrium to a monocentric structure and then shifts to a high-level spatial equilibrium with a polycentric structure. His theoretical conjecture has been supported by both simulations [27] and empirical studies [28].

A polycentric structure improves economic performance more in larger cities according to the theoretical predictions outlined above. However, empirical analyses that have directly examined the mediating effect of city size have not always supported these theoretical conjectures. In the city proper or metropolitan scale on which our study focuses, neither Zhang, Sun, and Li's (2017) work nor Lee and Gordon's (2007) study identified a significant interaction effect of city size on the relationship between economic performance and polycentricity [4,12]. However, Meijers and Burger (2010) found that the contribution of polycentricity to productivity is greater in smaller metropolitan areas than in larger metropolitan areas [2]. At the larger scale, Li and Liu (2018) as well as Sun and Li (2016) found that the relation between economic performance and polycentricity varied with different population sizes or densities at the prefecture city level [11,20], while Wang, Sun, and Zhang (2020) found evidence that polycentricity also boosts positive economic performance when regions have a larger population at the level of city cluster [29].

Otherwise, we also find some attempts to identify the moderating effect of city size between other dimensions of urban spatial structure and economic performance. Lee and Gordon (2007) revealed that more dispersion leads to higher growth rates as metropolitan areas grow [12], while Meijers and Burger (2010) and Li and Liu (2018) did not find any evidence of such an effect in the relationship between dispersion and economic performance by using population or density as interaction factors [2,11].

2.4. Existing Gaps

First, unlike theoretical advancements, the heterogeneity in the economic efficiency of polycentricity at the city proper or metropolitan level has not been strongly emphasized in the empirical literature. In particular, evidence concerning the moderating effect of city size on the relationship between urban spatial structure and economic performance is mixed and needs more robust empirical testing [2,4,10,16,19,20].

Second, until recently, very few studies on economic performance and spatial structure considered the full process of polycentric development along its two dimensions—the local reclustering of employment or the population after decentralizing away from the main city center. Studies have tended to borrow the framework of Meijers and Burger (2010) and to consider polycentricity to be a dimension of the distribution of economic activity [2]. Such approaches are crude when we want to know which channel plays a significant role in determining the economic effects of polycentricity. It is critical to distinguish whether polycentricity leads to economic gains because it diminishes the externalities from agglomeration through decentralization, because it diminishes agglomeration externalities through the gains from the positive externalities associated with reclustering, or because of both mechanisms. A complete exposition of polycentric evolution involves decentralization away from the CBD and then reclustering in several high-density areas, which has not been carefully tested.

Third, the estimation methods that most researchers have relied on to identify the causal association between spatial structure and economic performance have shortcomings. Limited by data availability, the bulk of early research results comes from cross-sectional models [2,4,10,12] and is likely biased because of omitted time-independent variables. Furthermore, many studies have examined the spatial distribution of the population rather than of employment [2,10,16]. The spatial distribution of the population has a less direct logical connection with economic output (especially as measured by GDP) than that of employment, given that spatial frictions mainly arise in the labor market.

We provide an integrated treatment of these gaps, and our starting point is to provide rigorous evidence on the relationship between the spatial structure of employment and economic performance, particularly at the level of the city proper in the Chinese context. In addition, we endeavor to connect the empirical work more strongly with geographers' and economists' theory of the evolutionary stages of spatial structure by emphasizing the moderating effect of city size. We extend the analysis to tests of different aspects of the hypothesized polycentricity process by including the two dimensions of decentralization and reclustering. We are aware of the endogeneity issues related to these tests and therefore propose a two-way fixed-effects panel model and instrumental variables for the TSLS models.

2.5. Our Hypotheses

We present a set of theoretical hypotheses to guide the empirical work and to establish clear expectations. Polycentricity is the result of a shift in the balance between the centrifugal forces that cause decentralization and the centripetal forces that lead to reclustering. We adopt the seminal framework established by Anas et al. (1998) and Lee (2007) to capture this dynamic [18,19]. To reiterate, the two dimensions of the metropolitan-level spatial structure are centralization versus decentralization and clustering versus dispersion (Figure 2). We can classify urban spatial structures into the following four types based on these two dimensions: monocentric (centralized and dispersed); sprawling (decentralized and dispersed); polycentric (decentralized and clustered); and monocentric with obvious subcenters (centralized and clustered). Using these four spatial structure types instead of simple dichotomies makes the differentiation of the processes at work both easier and clearer.

The relation between economic performance and the urban spatial structure is a dynamic balance between the positive and negative externalities of agglomeration. Polycentricity can be understood as an effective way to reduce agglomeration costs because it involves urban decentralization. In addition, economic productivity can be enhanced due to the reclustering of the population or of employment in subcenters through the mechanisms of sharing, matching, and learning [30]. On the other hand, polycentric structures also have the potential to harm labor productivity, given that decentralization may damage the agglomeration economies of the main center and lead to increasing transaction costs between centers.

The trade-off between agglomeration economies and agglomeration diseconomies is highly dependent on city size. We posit that which urban spatial structure is most efficient varies with city size. As cities grow, the negative externalities from agglomeration in the main center exceed the positive externalities. Decentralization can help reduce these agglomeration diseconomies, and reclustering can lead to gains through the scale effect among subcenters. Therefore, as long as cities are small enough that the benefits of agglomeration economies arising from the high level of concentration in the main city center exceed the corresponding costs, polycentricity likely undermines economic gains. In other words, it may not be possible for a city to reach a sufficiently large scale that the losses incurred from decentralization are outweighed by the positive agglomeration effects generated by subcenters (i.e., the metropolitan economy may be too small to be divided, and therefore, the sum of the parts is not greater than the centralized whole). Based on this theoretical argument, we predict that only when decentralization and reclustering are combined in sufficiently large cities can polycentricity foster greater economic development.

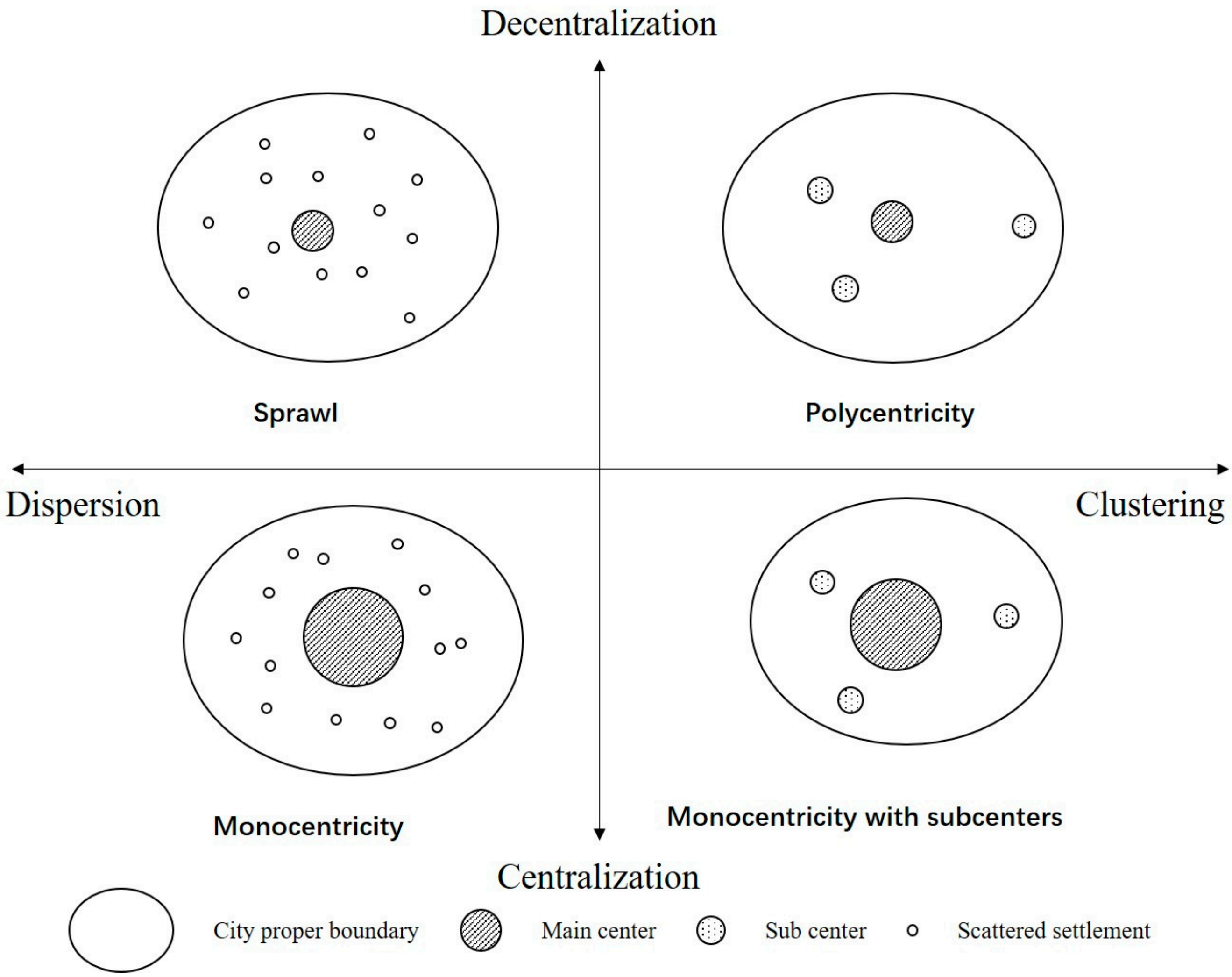

Figure 2. Spatial structure dimensions.

3. Methods and Data

Our methodological framework is organized as follows (Figure 3). First, we collect the multi-source data and determine the research scale in Section 3.1. Second, we clarify the concept of urban spatial structure and expound its measurement for our research in Section 3.2. Finally, we carry out the performance analysis by proceeding with the basic model, robustness test, and discussions (the models are listed in Section 3.3, and the results are shown in Section 4).

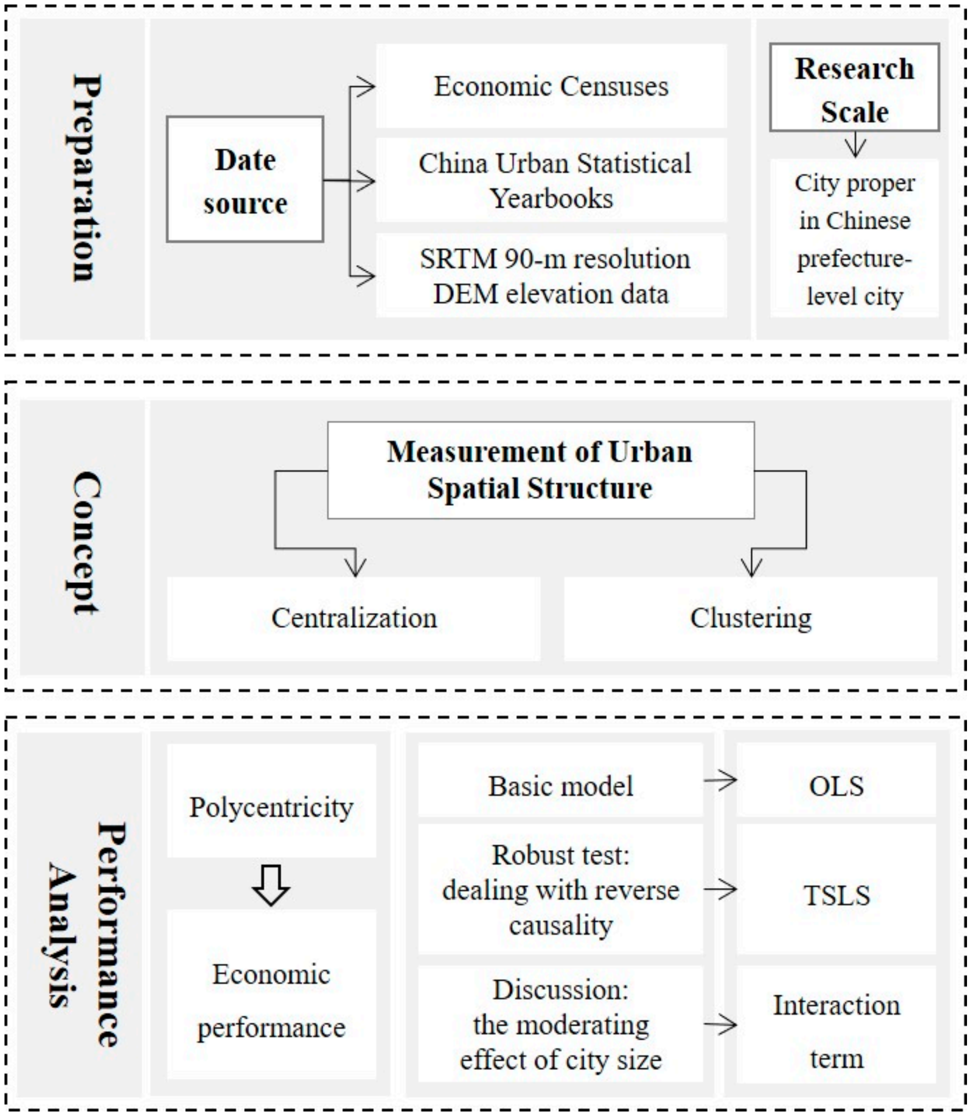

Figure 3. Methodological framework.

3.1. Data Sources and Research Scale

The accessibility of the labor market plays an important role in the association between urban spatial structure and economic performance because commuting creates friction between economic activities and space. Therefore, the distribution of labor is a key variable for economic productivity. We draw upon the Economic Censuses of 2004, 2008 and 2013 to calculate the urban spatial structure. The Economic Census is unique in China due to its provision of microlevel enterprise data, it contains detailed information on legal manufacturing and service entities in China, such as their postal code and the number of employees at each firm. Using this information, we can obtain the number of employees in each postal code zone for further calculation.

In addition to the availability of employment data with finer geographical scales, China is a quite suitable case for this study. China has many cities of all sizes, which could provide rich evidence for testing the effect of the heterogeneity of city size on the economic performance of polycentricity. Further, a reliable academic examination is urgently needed for the future development of ubiquitous polycentric planning practice in China.

As to the research scale, metropolitan areas are the preferred spatial unit for the analysis of economic performance because they are economically integrated areas. As a metropolitan area is not precisely defined in China, the concept of an administrative city (prefecture-level city) was more commonly used in the early literature. However, prefecture-level cities not only include highly urbanized subunits (cities proper, named Shixiaqu) but also contain a certain area of peripheral, semirural, and rural areas (county area, named Xian). Thus, we choose the city proper in the prefecture-level city as our second-best choice in terms of research scale as it is comparable to the metropolitan scale. The administrative divisions of 2008 (the middle year of our study time span) are taken as the standard and thus our full sample totals 287.

The choice of the analytical unit scale to be used for the spatial structure calculations is also of great importance. A unit that is too large averages important differences in the employment distribution within the area. To obtain sufficient precision with the available data, we choose postal code zones as our unit of analysis and sum the number of jobs in each unit to calculate our urban spatial structure indices.

3.2. Measurement of Urban Spatial Structure

We operationalize centralization and clustering by using the indices proposed in existing studies (summarized in Table 1). Centralized cities can feature dispersion or clustering outside the CBD, and clusters may be located near the CBD or away from the CBD. Compared with using polycentricity directly [2,4,5], we split the polycentricity into the dimension of decentralization and clustering. This approach gives up gaining the direct results of the extent to which polycentricity improves economic performance. However, to further investigate the mechanism and contribute to the early literature, we believe that it is worth using two dimensions to describe polycentricity.

Figure 4 illustrates the calculation process and symbol interpretation of the centralization and clustering indices.

All the indices are time-variant, as both the location of the CBD and the density of employment in each postal code vary across years. Similar to Wheaton (2004) [31], we use a virtual urban area boundary that contains 98 percent of all employment and excludes mostly low-density areas in outlying locations.

The centralization–decentralization dimension contains location information: it measures the extent to which employment is centralized near the CBD. For the purpose of creating our indices, the CBD is defined as the postal code with the highest employment density. The modified Wheaton index (MWI) and modified weighted average distance from the CBD (MADC) both measure how quickly the cumulative share of employment increases from the CBD to the urban edge [31,32]. The larger these two indices are, the more centralized the city is. A value of 1 indicates that all employment is concentrated in the center. When calculating the MWI, all postal code zones should be sorted by their distance to the CBD from nearest to farthest.

Table 1. Indices for the two dimensions of polycentricity.

Centralization indices	
Modified Wheaton index [31]	$\mathrm{MWI} = \frac{\sum_{i=1}^{n} E_{i-1}DCBD_i - \sum_{i=1}^{n} E_i DCBD_{i-1}}{DCBD^*}$
Modified weighted average distance from the CBD [32]	$\mathrm{MADC} = 1 - \sum_{i=1}^{n} \frac{e_i}{E} * \frac{DCBD_i}{DCBD^*}$
Clustering indices	
Delta index [32,33]	$\mathrm{DELTA} = \frac{1}{2}\sum_{i=1}^{n}\left\lvert \frac{e_i}{E} - \frac{a_i}{A} \right\rvert$
Gini coefficient [34,35]	$\mathrm{GINI} = \sum_{i=1}^{n} E_i A_{i-1} - \sum_{i=1}^{n} E_{i-1} A_i$

Notes: The zip code zone with the highest density of employment in each city is defined as the CBD. Symbols: ei: number of employed persons in zone i; E: total metropolitan employment; ei/E: share of metropolitan employment in zone i; Ei: cumulative share of employment in zone i; ai: land area of zone i; A: total metropolitan land area; ai/A: share of metro land area in zone i; Ai: cumulative share of land area in zone i; DCBDi: distance between zone i and the CBD; DCBD*: distance between the outermost zone and the CBD (city proper radius); n: number of zones (zip code zones).

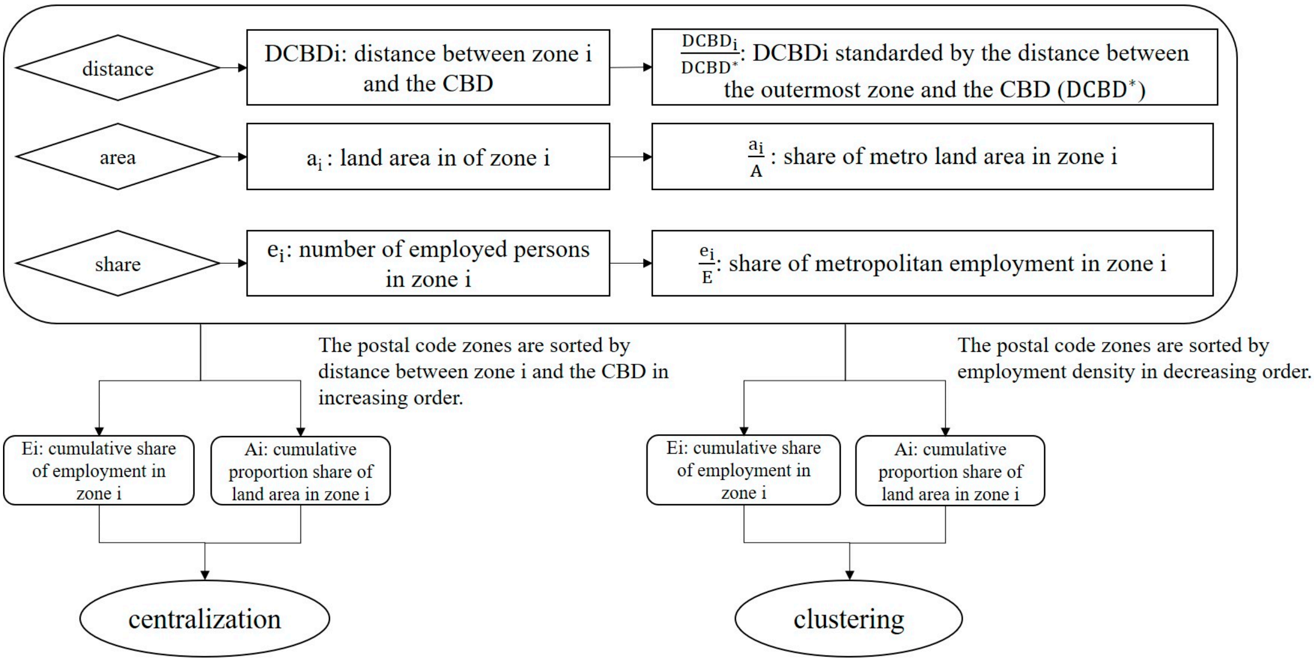

Figure 4. Calculation progress of centralization and clustering.

The clustering–dispersion dimension contains the information on the degree of agglomeration in the urban spatial structure. It captures the extent to which metropolitan employment is disproportionately located in areas with different densities and is measured by the Gini coefficient and Delta index in our paper [32–35]. The postal code zones are sorted by employment density in decreasing order.

3.3. Models

We rely on the Cobb–Douglas production function, which uses physical capital (measured as the physical capital stock per worker, $\frac{K}{L}$) and human capital (measured as the number of middle school students per 10^4 persons, $\frac{H}{L}$) as the most important production factors for economic growth. In addition to these production factors, economic productivity also influences economic performance by determining the efficiency with which these production factors are used. Therefore, the degree of government intervention (G), which is measured as the ratio of government consumption to GDP, is added to our model. Agglomeration has also traditionally been considered a key determinant of economic productivity. Population (POP) is a conventional aspect of agglomeration. We also add the quadratic term for population to identify the "optimal city size" with decreasing returns. Our main concern is the urban spatial structure variables (STU, including centralization and clustering), which we consider to be the structure of agglomeration. The econometric model is specified as follows:

$$\ln\left(\frac{GDP}{L}\right)_{it} = \pi + \alpha \ln\left(\frac{K}{L}\right)_{it} + \beta \ln\left(\frac{H}{L}\right)_{it} + \gamma G_{it} + \delta \ln(POP)_{it} + \varepsilon[\ln(POP)_{it}]^2 + \epsilon \ln(STU)_{it} + \theta_i + \vartheta_t + \mu_{it} \quad (1)$$

where θ_i and ϑ_t are time and individual fixed effects, respectively. In Equation (1), STU includes two dimensions, namely, centralization and clustering. The coefficient on centralization is expected to show whether decentralization reduces the negative externalities of agglomeration and is thus helps improve labor productivity. The clustering term tests whether clustering is associated with better economic performance. Descriptive statistics for both the dependent and the independent variables are shown in Table 2.

Table 2. Descriptive statistics of the variables.

Variable Name	Description	Mean	S.D.	Min	Max
$\ln\left(\frac{GDP}{L}\right)$	GDP per worker in yuan (ln)	11.62	0.527	9.527	13.95
$\ln\left(\frac{K}{L}\right)$	Physical capital stock per worker in 10^4 yuan (ln)	2.516	0.579	0.469	4.787
$\ln\left(\frac{H}{L}\right)$	Number of middle school student per 10^4 persons	6.868	0.395	4.904	8.017
G	Ratio of government consumption to GDP	100%	0.113	0.0720	0.0200
ln POP	Population in 10^4 persons	4.558	0.774	2.654	7.499
lnMWI	Centralization index 1	0.484	0.169	−0.69	0.688
lnMADC	Centralization index 2	0.579	0.084	0.111	0.688
lnDELTA	Clustering index 1	0.461	0.109	0.0250	0.646
lnGINI	Clustering index 2	0.517	0.111	0.0250	0.666

Consistent with the theoretical assumptions proposed by geographers and economists, the urban spatial structure becomes polycentric as the urban population grows. Therefore, we consider the moderating effect of city size on the causal link between the urban spatial structure and labor productivity by introducing interaction terms into Equation (1). The interaction terms test whether and how the partial effect of the spatial structure on economic performance depends on the size of the urban population, as shown in Equation (2). For example, $\rho > 0$ implies that an increase in population yields a higher increase in labor productivity for more centralized/clustered cities and vice versa.

$$\begin{aligned}\ln\left(\tfrac{GDP}{L}\right)_{it} &= \pi + \alpha\ln\left(\tfrac{K}{L}\right)_{it} + \beta\ln\left(\tfrac{H}{L}\right)_{it} + \gamma G_{it} + \delta\ln(POP)_{it} + \varepsilon[\ln(POP)_{it}]^2 + \epsilon\ln(STU)_{it} + \rho\ln(STU)_{it}\times\ln POP + \theta_i + \vartheta_t + \mu_{it} \\ &= \pi + \alpha\ln\left(\tfrac{K}{L}\right)_{it} + \beta\ln\left(\tfrac{H}{L}\right)_{it} + \gamma G_{it} + \delta\ln(POP)_{it} + \varepsilon[\ln(POP)_{it}]^2 + \epsilon\ln(STU)_{it} + [\epsilon + \rho\ln POP]\times\ln(STU)_{it} + \theta_i + \vartheta_t + \mu_{it}\end{aligned} \quad (2)$$

4. Empirical Results

4.1. Basic Models

Table 3 shows the results of our baseline models, which use OLS regressions with individual and time fixed effects. The results for Models 1 and 3 indicate that the spatial dimensions of centralization/clustering do not appear to be directly associated with higher economic productivity. In Models 2 and 4, we introduce interaction terms (lnPOP × lnMWI and lnPOP × lnDELTA) to test the moderating effect of city size on the relation between economic performance and the urban spatial structure. In Model 4, the positive and significant coefficient on the interaction between lnPOP × lnDELTA confirms one of our hypotheses: in large cities, having more clusters boosts economic development. In Model 5, we introduce both the centralization and clustering indices and the interaction terms between spatial structure and city size. The interaction effect between population and centralization is significant and negative. This indicates that decentralization can indeed diminish negative agglomeration effects and improve urban productivity. The positive and significant influence of the interaction term between lnPOP and lnDELTA implies that population size increases the effect of clustering on urban productivity. More specifically, decentralization and clustering (i.e., a polycentric spatial structure) appear to be more helpful for urban economic performance only when the city reaches a certain population size. Another source of concern is that the effect of city population on economic performance is an inverted U shape, which confirms the existence of an optimal city size. All other significant control variables have the expected signs.

Table 3. OLS regressions with time and city fixed effects.

	(1)	(2)	(3)	(4)	(5)
Dependent Variable: ln(GDP/L)	**FE**	**FE**	**FE**	**FE**	**FE**
ln(K/L)	0.5816 ***	0.5828 ***	0.5817 ***	0.5807 ***	0.5860 ***
	(0.035)	(0.035)	(0.035)	(0.035)	(0.034)
ln(H/L)	0.0830 **	0.0834 **	0.0841 **	0.0869 ***	0.0873 ***
	(0.033)	(0.034)	(0.034)	(0.033)	(0.033)
G	−0.7232 *	−0.7189 *	−0.7224 *	−0.7120 *	−0.6919 *
	(0.375)	(0.374)	(0.375)	(0.377)	(0.374)
lnPOP	1.1806 ***	1.2396 ***	1.1816 ***	0.9285 **	1.0014 ***
	(0.317)	(0.372)	(0.316)	(0.362)	(0.355)
lnPOP × lnPOP	−0.0993 ***	−0.1027 ***	−0.0993 ***	−0.0883 ***	−0.0961 ***
	(0.030)	(0.032)	(0.029)	(0.031)	(0.032)
lnMWI	−0.0283	0.2361			1.3465 *
	(0.079)	(0.619)			(0.693)
lnPOP × lnMWI		−0.0619			−0.3322 **
		(0.139)			(0.166)
lnDELTA			−0.0248	−1.4951 *	−2.7848 ***
			(0.137)	(0.858)	(1.062)
lnPOP × lnDELTA				0.3338 *	0.6525 ***
				(0.189)	(0.246)
Time FE	Y	Y	Y	Y	Y
City FE	Y	Y	Y	Y	Y
Constant	6.5128 ***	6.3167 ***	6.4983 ***	7.3782 ***	7.1902 ***
	(0.933)	(1.127)	(0.918)	(1.085)	(1.058)
Observations	734	734	734	734	734
R-squared	0.873	0.873	0.873	0.874	0.875
Number of cities	273	273	273	273	273
Hausman test Prob > chi^2	0.000	0.000	0.000	0.000	0.000

Note: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. A total of 103 observations (city × year) are missing due to the lack of zip code information in the economic census data, and another 24 observations are missing due to the lack of relevant control variables in the China Urban Statistical Yearbooks (287 × 3 − 103 − 24 = 734). The Hausman test strongly indicates the rejection of the null hypothesis; therefore, a fixed effects model should be adopted instead of a random effects model.

4.2. Robustness Tests

The endogeneity of polycentricity in relation to better economic performance or to the omission of key variables are salient concerns and have the potential to significantly bias the coefficients. First, urban spatial structure and labor productivity are potentially related in two directions. The positive correlation between them may stem from the fact that cities with higher productivity are more likely to be decentralized and clustered. Second, although we included as many relevant control variables as possible and used a two-way fixed-effects model to control for unobservable time and city effects, some relevant variables may still be missing from the regressions.

Ordinary least squares (OLS) can suffer from the potential bias caused by reverse causality and omitted variables. TSLS estimation is a common method for reducing this potential bias. Therefore, we conduct a TSLS estimation by using an instrumental variable that is correlated with the potentially endogenous urban spatial structure but not with labor productivity.

Inspired by previous related research [36], topographic data could be a valid source of instruments for urban spatial structure. Thus, we use the SRTM 90-m resolution DEM elevation data gathered by the National Aeronautics and Space Administration (NASA) and the National Imagery and Mapping Agency (NIMA) to obtain the average slope of each postal code area in each Chinese city proper.

However, rather than directly adopting the average slope of terrain roughness, we designed a group of more relevant instruments. Generally, firms prioritize building in areas where the slope is less steep. In contrast, areas with steep inclines have high construction and usage costs; thus, they have a lower potential for becoming centers of employment concentration. Therefore, a less steep postal code area, i.e., a postal code area with a lower average slope, could probably attract more employment. We use (90°—the average slope of each postal code area) as a measure of potential employment to replace the actual employment in the corresponding postal code area. Then, based on the formulas for the urban spatial structure indices, we replace actual employment with each location's potential employment (90°—average slope) and then use these new indices as instrumental variables (IVs) for the urban spatial structure. A higher value for these IVs could be positively related to a higher level of centralization or concentration. The IVs are also time-variant, as the locations of the CBDs change over time.

Regarding the validity of the instruments, the slope of the surface is a natural feature and thus highly exogenous in relation to economic activities. Furthermore, we use topographic data from 2000, which are very unlikely to have been influenced by economic development after 2004; in addition, because of the height measurements taken by the SRTM 90-m resolution DEM elevation instruments are precise to approximately 16 meters (approximately the height of a five-story building), we can conclude that our slope measurements are unlikely to be affected by the built environment.

In Table 4, the Cragg–Donald F statistic shows that our instruments are relevant in most of our models. However, limited information maximum likelihood (LIML) estimation, which is less sensitive to weak IVs, is used in Table 5 to reduce the negative impact of weak IVs.

Table 4. The first stage of the IV regressions.

	lnMWI	**lnMADC**	**lnDELTA**	**lnGINI**
First-stage coefficients on the IVs	0.3014 ***	2.7629 ***	0.3525 ***	1.1047 ***
	(0.0319)	(0.7746)	(0.0386)	(0.4376)
Shea partial R^2	0.1645	0.0273	0.1559	0.0139
Anderson canon. corr. LM statistics	75.848 ***	12.591 ***	71.690 ***	6.396 **
Cragg–Donald Wald F statistics	89.209	12.720	83.419	6.374

Note: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$.

Table 5 confirms the results that we obtained from the OLS model. As the spatial structure variables are not shown to be endogenous by Durbin–Wu–Hausman tests, we conclude that the OLS estimations are more efficient. However, we present the TSLS results here as a robustness test.

Table 5. TSLS regression results.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Dependent Variable: ln(GDP/L)	**TSLS**	**TSLS**	**TSLS**	**TSLS**	**TSLS**
lnPOP	1.1767 ***	1.9634 ***	1.1790 ***	−1.1453	−1.4068
	(0.345)	(0.503)	(0.354)	(1.731)	(1.791)
lnPOP × lnPOP	−0.0991 ***	−0.1448 ***	−0.0993 ***	0.0017	0.0146
	(0.033)	(0.040)	(0.034)	(0.090)	(0.101)
lnMWI	−0.1272	3.4557 **			−0.6968
	(0.215)	(1.592)			(2.874)
lnPOP × lnMWI		−0.8217 **			0.1124
		(0.380)			(0.642)

Table 5. *Cont.*

	(1)	(2)	(3)	(4)	(5)
Dependent Variable: ln(GDP/L)	**TSLS**	**TSLS**	**TSLS**	**TSLS**	**TSLS**
lnDELTA			−0.6979	−14.2572	−14.9520 **
			(0.862)	(9.214)	(7.302)
lnPOP × lnDELTA				3.0653	3.2583 *
				(2.144)	(1.663)
Others	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y
City FE	Y	Y	Y	Y	Y
Observations	714	714	714	714	714
R-squared	0.872	0.860	0.864	0.795	0.777
Number of cities	253	253	253	253	253
Hausman Prob > chi2	1.0000	0.7408	0.9990	0.9407	0.9708

Note: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Twenty observations were removed because of they were the only observation in their group.

In addition, we also find that the results are mostly robust to alternative urban spatial structure indices (Table 6).

Table 6. Robustness to urban spatial structure indices.

	(1)	(2)	(3)
Dependent Variable: ln(GDP/L)	**FE**	**FE**	**FE**
lnPOP	1.1375 **	0.9224 **	1.1242 ***
	(0.446)	(0.361)	(0.422)
lnPOP × lnPOP	−0.0978 ***	−0.0909 ***	−0.0955 ***
	(0.032)	(0.031)	(0.032)
lnMADC	−0.3233		2.1723
	(1.377)		(1.813)
lnPOP × lnMADC	0.0495		−0.5319
	(0.306)		(0.426)
lnGINI		−1.6431 *	−2.7654 **
		(0.864)	(1.273)
lnPOP × lnGINI		0.3561 *	0.6315 **
		(0.193)	(0.301)
Others	Y	Y	Y
Time FE	Y	Y	Y
City FE	Y	Y	Y
Constant	6.7249 ***	7.4470 ***	6.6762 ***
	(1.486)	(1.092)	(1.377)
Observations	734	734	734
R-squared	0.873	0.874	0.875
Number of cities	273	273	273

Note: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.3. Discussion

The estimates suggest that the interactions between urban spatial structure and labor productivity are heterogeneous with respect to population size. Most models support the idea that in large cities, a decentralized and clustered structure performs better, which confirms that the relation between economic performance and polycentricity depends on the urban population size. Recalling our second hypothesis, there are two potential mechanisms for the larger economic influence of polycentric structures: decentralization diminishes the negative externalities of agglomeration, and reclustering in subcenters re-establishes the positive externalities through "borrowed size". Our results confirm both mechanisms. With the growth of the city population, whether employment is more clustered or dispersed matters just as much to urban economic performance as whether clustering occurs near the CBD.

To put our findings into context and enrich the academic and practical guidelines on the evolution of urban spatial structure, we provide the following discussion.

4.3.1. Discussion 1: Comparing Our Results with Those of Previous Studies

To the best of our knowledge, this paper is the first to verify the theoretical predictions at the city proper scale that polycentric structure improves economic performance more in larger cities. Referring to the previous works on a comparable scale, some argue that the effects of polycentricity on economic performance do not depend on city size [4,12], while others raise conclusions opposite ours [2].

First, one of the reasons for the different results could be the methods used. Due to data availability, we adopt panel data models instead of the cross-sectional models, as were used in previous works. The cross-sectional models are not as reliable as panel models because they are more likely to be biased.

Second, the different context of the study case could also affect the results. Our results contrast with those obtained by Meijers and Burger (2010) [2], who argued and empirically showed that polycentricity resulted in better economic performance in small metropolitan areas than in large metropolitan areas. They explained that the functional connections between urban subcenters in small metropolitan areas were denser than those in larger areas. This inconsistency may originate from differences in the developmental stages of the samples. Metropolitan areas in the United States are already mature; therefore, the influence of agglomeration economies and diseconomies is more balanced. Since the 1970s, American metropolitan areas have evolved toward polycentric spatial structures that are functional rather than morphological. In contrast, China is in the midst of fast-paced urbanization, and the share of the urban population has only recently surpassed that of the rural population. At this stage, the urban morphological spatial structure is evolving rapidly, and the surplus between agglomeration economies and diseconomies plays an important role in labor productivity.

Nevertheless, our results are in line with some findings on larger scales [10,20,29].

4.3.2. Discussion 2: City Size Threshold for a Positive Influence from Polycentricity

We attempt to find the city size threshold at which the economic influence of polycentricity changes from negative to positive. We specify the interactions between the urban spatial structure (centralization and clustering) and urban population size to capture potential heterogeneity (Model 5 in Table 3). We then calculate the marginal effect of lnSTU's contribution to economic performance as $\beta_{lnSTU} + \beta_{lnSTU \times lnPOP} \times$ lnPOP. As β_{lnSTU} and $\beta_{lnSTU \times lnPOP}$ are opposite in sign in all our models, the sign of lnSTU ($\beta_{lnSTU} + \beta_{lnSTU \times lnPOP} \times$ lnPOP) changes from negative to positive or from positive to negative as the population grows (see Figure 5). Simply put, when we set the estimated coefficient for lnSTU (i.e., $\beta_{lnSTU} + \beta_{lnSTU \times lnpop} \times$ lnpop) equal to zero, we obtain the critical point for this change. As Table 7 and Figure 5 show, centralization and dispersion (monocentricity) better facilitate economic performance only in small cities with fewer than approximately 600,000 residents. However, decentralization and clustering (polycentricity) are better structures for cities with more than 700,000 residents. Furthermore, the city size threshold for centralization is lower than that for clustering, which implies that for better economic performance, decentralization should occur before clustering in the urban structure evolutionary process.

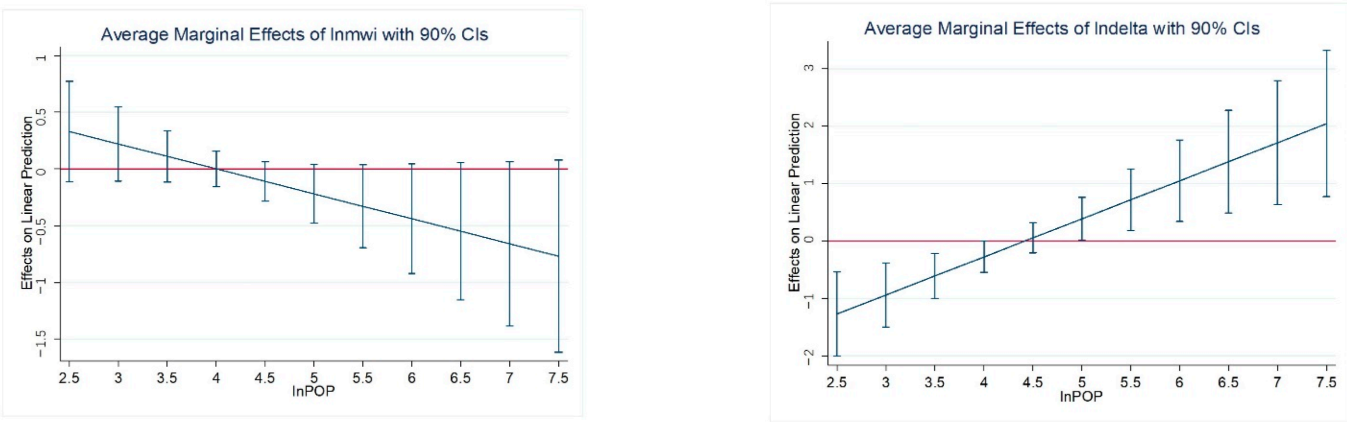

Figure 5. Marginal effects of the spatial structure (based on Model 5 in Table 3).

Table 7. Population threshold for the economic effects of the spatial structure.

	Table 3 Model 5
β(lnMWI)	1.3465
β(lnpop × lnMWI)	−0.3322
the threshold of city size for MWI	575,800
β(lnDELTA)	−2.7848
β(lnpop × lnDELTA)	0.6525
the threshold of city size for DELTA	713,700

According to a study on "ghost towns" using nighttime light data, unsuccessful new towns appear quite frequently around small-sized cities, such as Jiayuguan, Zhangye, Jiuquan, and Fangchengang [37]. We find that the populations of these cities are usually below 600,000 residents, which coincides with our findings. Thus, polycentricity strategies are planned too far ahead for small cities. Instead, monocentricity (centralization and clustering) could be better choice for these small cities.

4.3.3. Discussion 3: Optimal City Size Constrained by Different Spatial Structures

By adding the quadratic form of lnPOP and the interaction terms between lnPOP and the urban spatial structure variables, we can calculate the peak population point (P*, henceforth) that represents the optimal city size, as constrained by different spatial structures. Maximizing GDP per worker and holding the other control variables constant gives a peak size of

$$P^* = \frac{\beta_{\text{lnPOP}} + \beta_{\text{lnSTU}\times\text{lnpop}} \times \text{lnSTU}}{2 \times \beta_{\text{lnPOP}^2}}$$

As the mediating effect of city size on centralization is negative and that on clustering is positive, the peak size is larger for decentralized and clustered cities. Calculated on the basis of the estimates from Model 5 in Table 3, the results presented in Table 8 and Figure 6 support our hypothesis and indicate the peak points where GDP per worker is maximized for each quartile of the spatial structure indices in 2013. The peak population size increases as cities become more decentralized and clustered. To simplify the comparison, we define two hypothetical cities. The first is polycentric with a MWI value in Q1 and a DELTA value in Q3 (decentralized and clustered). The second city is monocentric and has its MWI value in Q3 and its DELTA value in Q1 (centralized and dispersed). The optimal population size in the polycentric city, under the chosen specifications, is twice as large as that in the monocentric city (584.13/253.86 ≈ 2.3).

Table 8. Peak city population size (in 10,000) relative to GDP per worker (2013).

Peak Population Size		Dispersed		Clustered
		DELTA in Q1	**DELTA in Q2**	**DELTA in Q3**
Decentralized	MWI in Q1	340.72	424.08	584.13
	MWI in Q2	286.60	356.72	417.04
Centralized	MWI in Q3	253.86	324.48	379.36

Note: Q1, Q2, and Q3 represent the lower quartile, median, and upper quartile, respectively.

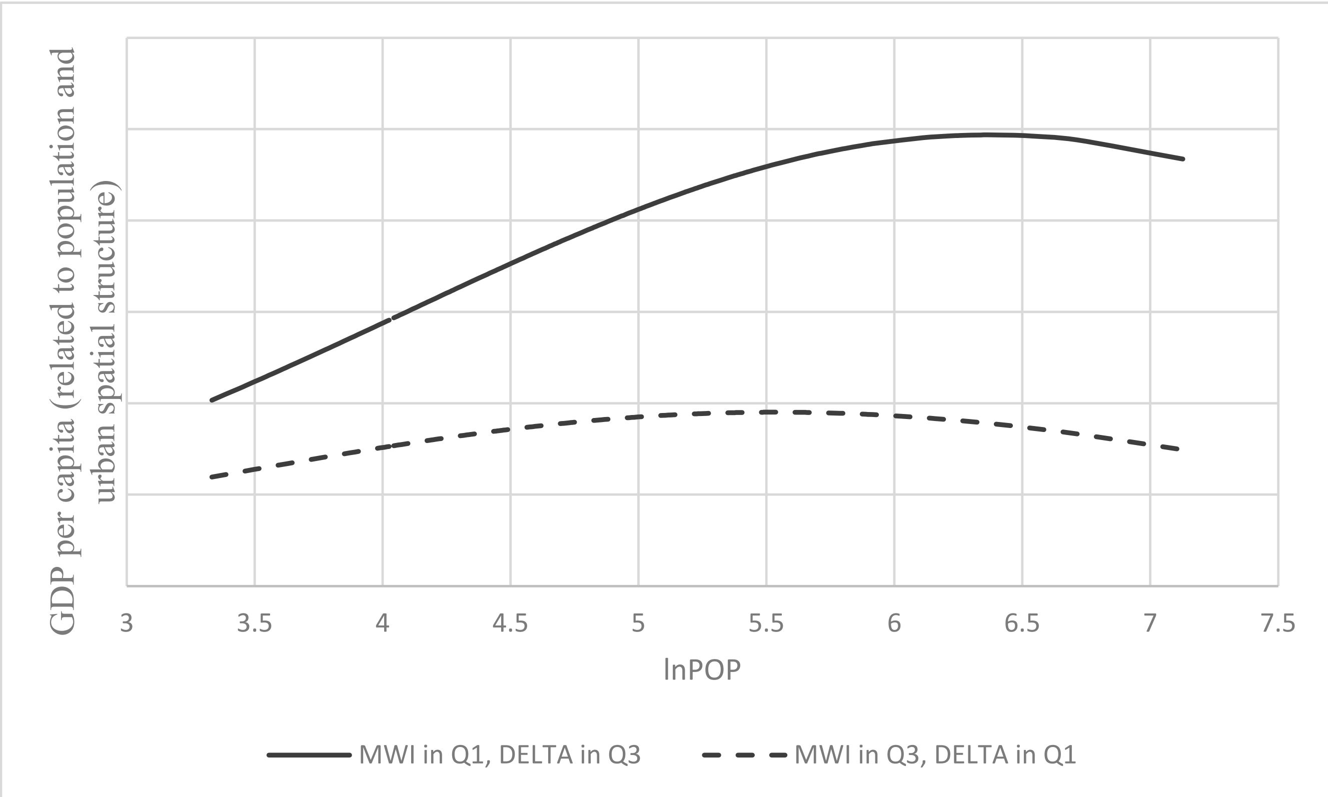

Figure 6. The inverted U shape in the relationship between size and economic performance for cities with different spatial structures.

As a validation of our results, we collect the estimated Chinese optimal city size raised by early works (Table 9). These numbers are very close to our findings.

Table 9. Optimal city size in the early literature.

Authors (Year)	Optimal City Size (in 10,000 Persons)
Wang and Xia (1999) [38]	100–400
Chen and Jiang (2002) [39]	100–400
Ma and Song (2003) [40]	100–200
Au and Henderson (2006) [41]	54.4–144
Liu (2007) [42]	270
Zhang and Xie (2017) [43]	200–500

4.3.4. Discussion 4: The Economic Significance of Urban Spatial Structure

Based on the results from Model 5 in Table 3, we aim to calculate the economic significance of urban spatial structure transformation, namely, how much profit is accrued when cities become more decentralized (a decrease in MWI) and more clustered (an increase in DELTA). Thus, we choose the following five Chinese cities with different population sizes as our study cases: Jiayuguan (200,000), Suizhou (500,000), Weinan (1 million), Wuhan (5 million), and Tianjin (8 million).

Table 10 confirms that the economic performance that results from the transformation of the urban spatial structure varies based on the urban population size. In small cities such as Jiayuguan (200,000), each 1% reduction in centralization results in a 1.1 thousand yuan decrease in GDP per capita, and a 1% increase in clustering also results in a 2.6 thousand yuan decrease in GDP per capita. In Suizhou (500,000), the loss values are 0.04 and 0.2 thousand yuan per capita, respectively, which are both smaller than those in Jiayuguan. However, in larger cities, the decentralization and clustering processes create an increase in economic benefits, and larger cities earn more. The effects of both the 1% decrease in centralization and the 1% increase in clustering in Tianjin (8 million) are double those in Wuhan (5 million). These values are all of economic significance and thus cannot be ignored. These economically significant outcomes are also confirmed when we consider a change of one standard deviation.

Table 10. Economic benefits of spatial structure in different sized cities.

City	Jiayuguan	Suizhou	Weinan	Wuhan	Tianjin
Population (million persons)	0.2	0.5	1	5.1	8.2
GDP per capita (thousand yuan/person)	311	93.8	157.2	195.2	293.1
Change in GDP per capita with a 1% decrease in centralization (thousand yuan/person)	−1.1	−0.04	0.3	1.4	2.6
Change in GDP per capita with a 1% increase in clustering (thousand yuan/person)	−2.6	−0.2	0.3	2.5	4.7
Change in GDP per capita with a decrease of one standard deviation in centralization (thousand yuan/person)	−18.5	−0.7	0	0.2	43.7
Change in GDP per capita with a decrease of one standard deviation in clustering (thousand yuan/person)	−28.1	−2.4	3.7	27.4	50.9

5. Conclusions and Policy Implications

This paper provides a deeper understanding of and more robust evidence for the link between spatial structure and economic performance in the Chinese city proper, specifically in terms of the two dimensions of polycentricity, namely, centralization and clustering. Based on the China Economic Census Database that covers 2004, 2008, and 2013, we use a two-way fixed-effects panel model to examine the aforementioned causal link. After controlling for the main characteristics of the cities that may influence both urban spatial structure and labor productivity, we find that polycentricity contributes more to economic performance in larger cities. In contrast, building strong CBDs is a more effective way to promote urban economic development in small cities during the initial stages of development. In addition, we find that the optimal population size increases when cities transform from a monocentric structure to a polycentric structure.

This finding is particularly relevant in China, where a number of cities have focused on shifting employment away from the main centers and developing subcenters. Our findings suggest that polycentricity strategies are effective policy instruments for addressing the limitations imposed by urban growth, such as congestion and pollution. At the same time, decentralization and clustering constrain the population growth process and substantially influence the optimal population size. Polycentricity is reasonable and even desirable for large cities but not for small cities. Urban planners should be cognizant of the costs of developing multicenter plans in small cities.

However, some things remain to be carried out for future research. First, as well as economic performance, environmental and social performance are also worth paying attention to. Second, individual behavior analysis on how employees choose between possible locations and thus how the individual choice effects the economic performance are promising with the popularization of big data.

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