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Suburbanization and Subcentering of Population in Beijing Metropolitan Area: A Nonparametric Analysis

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Abstract: This study focuses on the suburbanization and subcentering of population and examines the nature of spatial restructuring in terms of the population distribution in the Beijing metropolitan area. Instead of the classic density function approach, we employ the nonparametric analysis to characterize the spatial pattern of population densities in the Beijing metropolitan area and identify the suburban subcenters. Our findings suggest that the population has spread with rapid urban growth in the Beijing metropolitan area, and the compact urban form has been replaced by a more dispersed polycentric spatial distribution. However, compared with the decentralization of western cities, the spatial extent of the decentralization of population in the Beijing metropolitan area is quite limited. The rapid growth of population in the near suburbs has expedited the sprawl of the central city, with a larger central agglomeration of population dominating the metropolitan area. In this sense, the spatial pattern of the Beijing metropolitan area is still characterized by the continuous compactness. However, our findings do provide the evidence that the city has been turning to a polycentric structure. We find significant population subcenters have emerged in the suburbs of Beijing since the 1980s. But the polycentricity emerged in the Beijing metropolitan area is very different by nature from that observed in Western cities. The subcenters emerged are adherent to the development scheme planned for the city, so it can be referred to as the so called ′planned polycentricity′.

Keywords: suburbanization; population subcenters; polycentricity; urban spatial structure; Beijing metropolitan area

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1 Introduction

Since the late 1980s, there has been revitalized interest in the analysis of urban spatial structure in urban studies. Anas *et al*. (1998) attributed this to the fact that urban growth patterns in the developed countries have undergone a ′qualitative change′ over the last two decades, characterized by the emergence of increasingly large and diversified suburban subcenters that are in direct competition with the traditional city center, with the continual decentralization of both population and employment, which have profoundly changed the spatial structure of contemporary metropolitan areas and led to a more dispersed and polycentric urban form (Coffey and Shearmur, 2001). Although the nature, causes and consequences of this spatial change have still been under debate (Lee, 2007; Shearmur *et al*., 2007), the polycentric urban phenomenon has been extensively documented and empirical regularities are evident in the literature (Anas *et al*., 1998; McMillen and Smith, 2003; Baumont *et al*., 2004; McMillen, 2004). Policy concerns have also arisen regarding the changing urban structure, given the social, environmental and economic impacts involved (Lang and Lefurgy, 2003). However, empirical

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studies conducted so far are mostly based on the urban experience of the Western countries, while few studies have been carried out on the developing urban world, and much less has been known about how cities in the developing countries have changed over the decades, and whether the similar development trend to that of western metropolitan evolution is also apparent there. Much of the recent scholarship has revealed that, responding to similar global forces of economic restructuring and technology advances, such urban processes as decentralization and suburbanization have also been observed in the cities of the developing countries, and new urban elements such as suburban shopping malls and new towns have emerged too, which has been cited as the evidence of the urban convergence hypothesis that claims cities around the world are becoming alike and converging to a set of socio-spatial attributes similar to those of Western cities (Cohen, 1996; Dick and Rimmer, 1998; Ma and Wu, 2005). However, the convergence thesis has been widely challenged and criticized. As Ma and Wu (2005) as well as Freestone and Murphy (1998) argued, despite a general convergence of suburbanization and metropolitan re-centering trends across countries, the nature of the urban forms emerging, the underlying driving forces and the processes involved are culturally and historically specific in different countries and embedded in local economic and political systems. So, some comparative analysis looking across different contexts of the developed and developing economies to understand more thoroughly the changing spatial structure of contemporary metropolitan areas are still needed and of great interest.

The decentralization of population from the inner city into the suburbs in Beijing since the 1980s has been revealed in previous studies (Wang and Zhou, 1999; Feng *et al*., 2008; Feng *et al*., 2009). However, the form and extent of this suburbanization have not been well-understood. The general trend to suburbanization may mask significant rearrangement of the spatial distribution of population. Local, asymmetric, trends would be highly relevant as the city has become significantly more differentiated and segregated than before over the post-reform period, which is most clearly reflected in the residential space (Ma and Wu, 2005). Some recent studies, e.g. Feng *et al*. (2009), have found the transition of the urban spatial structure of Beijing towards polycentricity in terms of the population distribution, which is similar to the trends in most western cities. However, the subcentering of population in the Beijing metropolitan area has not yet been examined in depth in those studies, and more detailed investigations into the spatial dynamics of population distribution are still needed. Besides, previous studies usually applied the parametric analysis to investigate the evolution of urban population distribution, e.g. the negative exponential function or its relatives. But the parametric analysis requires the specification of a global function (urban population density function) to fit a model to urban densities, which usually pre-assumes a monocentric and symmetrical urban structure, therefore it can not account for the differences of population densities in different directions or for the existence of possible subcenters (local variation). The rigidity and drawbacks of the parametric approach has motivated more flexible techniques applied to modeling urban population densities, known as nonparametric procedures (McMillen and McDonald, 1997; McMillen, 2001). The flexibility of nonparametric procedures has distinctive advantages for modeling the polycentric structure of the contemporary decentralized urban area.

This study presents an empirical analysis on the pattern of population distribution in the Beijing metropolitan area and its evolution in the post-reform era, by employing the nonparametric analysis. It focuses on the suburbanization and subcentering of population in the Beijing metropolitan area. The objective is to understand better the changing characteristics of population distribution, given the context of the rapid urban growth and the economic and societal transition, and to offer further understanding of the spatial organization of contemporary urban areas based on the evidences that depart from the North American and European experience.

2 Materials and Methods

2.1 Study area

The study area is the Beijing metropolitan area, the boundary of which is still not clearly defined in the relevant literature. Considering the rapid urbanization of the city during the past decades, we define the Beijing metropolitan area to include the urban area and its adjacent outer suburbs, which contained 12 districts by 2010 (Dongcheng, Xicheng, Chaoyang, Haidian, Shijingshan, Fengtai, Changping, Shunyi, Tongzhou, Mentougou, Fangshan, Daxing) (Fig. 1).

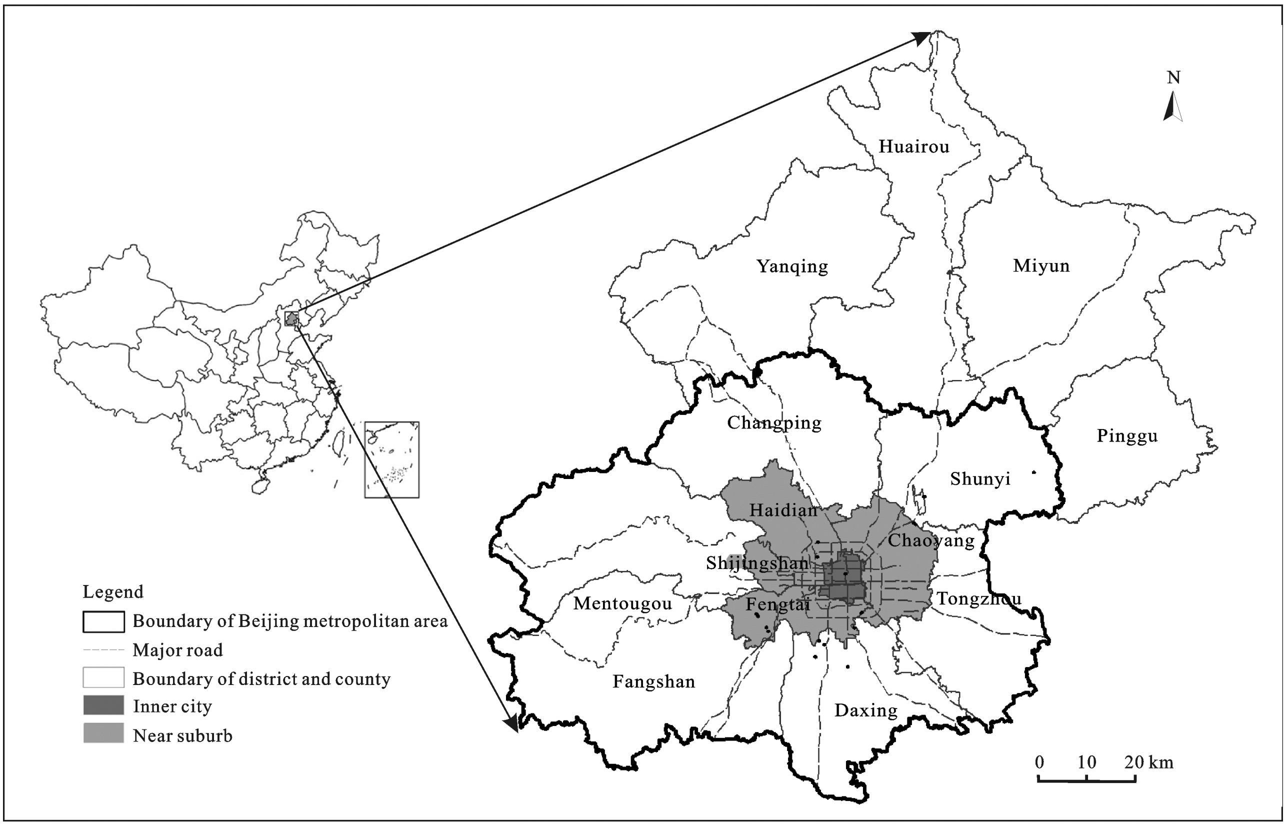


Fig. 1 Location of study area

2.2 Data sources

The population data used in this study were drawn from the 1982, 1990, 2000 and 2010 population censuses of Beijing. The data are at the subdistrict (jie dao in Chinese), town (zhen in Chinese) and township (xiang in Chinese) level. The subdistrict, town and township (hereafter referred to as the subdistrict) are the finest geographical units where the census data are available. For each subdistrict, we observed the tract′s centroid and land area. The distance was measured as a straight line distance between the centroids of tracts. The spatial boundaries of subdistricts were aggregated in some cases to accommodate to the changing administrative boundaries of subdistricts over time. Table 1 provides the summary statistics for our data.

The Beijing metropolitan area covers more than 9 000

Table 1 Summary statistics for subdistricts

	Year	Mean	Minimum	Maximum	S.D.	Total
Population (10^3 person)	1982	47.57	5.78	457.10	43.90	7992.27
	1990	46.28	6.03	292.39	35.85	9440.59
	2000	51.75	4.22	214.20	36.92	12006.09
	2010	75.33	2.47	359.42	61.98	18005.01
Area (km^2)	1982	54.26	0.98	383.50	61.66	9116.30
	1990	44.69	0.98	383.50	57.57	9116.30
	2000	39.29	0.94	383.50	54.75	9116.30
	2010	38.14	0.94	383.50	53.43	9116.30
Density (10^3 person/km^2)	1982	7.71	0.04	60.40	13.27	–
	1990	7.83	0.04	52.71	11.55	–
	2000	8.70	0.03	40.47	10.28	–
	2010	10.12	0.02	40.69	10.83	–

km^2 with nearly 8.0 × 10^6 persons in 1982 and over 1.8 × 10^7 persons in 2010. There were 168, 204, 232 and 239 tracts in 1982, 1990, 2000 and 2010 respectively. The increase of the number of tracts was mainly due to the division of large subdistricts into smaller ones for the administrative purposes. The subdistrict tracts vary in land area from less than one square kilometer to hundreds of square kilometers. There was similarly great variation in the population of tracts, with the mean at about 50 000 persons before 2000. After 2000, the mean population of subdistricts has increased greatly from 51 750 persons in 2000 to 75 330 persons in 2010. The average population density of tracts increases over time, from 7710 persons/km^2 in 1982 to 10 120 persons/km^2 in 2010. While the lowest density remains generally the same through the years, marked shifts in the location of population can be observed at the other end of the distribution: the highest density drops greatly by 33% from 60 400 persons/km^2 in 1982 to 40 690 persons/km^2 in 2010.

2.3 Analytical methods

2.3.1 Characterizing population density patterns using local regression

This study applies a nonparametric procedure, local regression (loess) or locally weighted regression (lowess), to investigate the pattern of population distribution and its evolution in the Beijing metropolitan area. The problem with the parametric analysis using the density function mainly arises from the rigidity of the pre-assumed functional form. The advantage of nonparametric procedures lies in that it is not required to specify a global functional form to fit the data, this can reduce misspecification bias to a large extent and allow greater flexibility than traditional modeling methods (McMillen and McDonald, 1997).

Local regression was originally proposed by Cleveland (1979) and further developed by Cleveland *et al.* (1988), and Cleveland and Grosse (1991). The procedure approximates a complex regression surface with a series of local approximations (McMillen and McDonald, 1997). Such a local approximation is obtained by fitting a low-degree polynomial to a subset of the data within a chosen neighborhood around the point whose response is being estimated, using weighted least squares, with more weight given to nearby observations. The size of the neighborhood determines the fraction of the data included in the local fitting, which is also called the smoothing parameter, and controls the smoothness of the estimated surface. The smoothing parameter can be selected using a variety of methods, most of which choose the parameter value to minimize a specific criterion. In this study, we use the bias-corrected *AIC* criterion (AIC_C) proposed by Hurvich *et al.* (1998), formulated as

$$AIC_C = \log(\hat{\sigma}^2) + 1 + \frac{2(\mathrm{Trace}(L)+1)}{n - \mathrm{Trace}(L) - 2} \qquad (1)$$

where $\hat{\sigma}^2$ is the error mean square; n is the number of observations; L is the smoothing matrix that satisfies $\hat{y} = Ly$; Trace (L) denotes the trace of matrix L; y is the vector of observed values and $\hat{y}$ is the corresponding vector of predicted values of the dependent variable. Within the specified neighborhood, observations are given weights that decline with distance. The weight function used in this study is a tricube function given by

$$w_i = \frac{32}{5}\left(1 - \left(\frac{d_i}{d_{\max}}\right)^3\right)^3 \qquad (2)$$

where w_i denotes the weight given to observation i; d_i represents the distance between observation i and the point of the local fitting, and $d_{\max}$ is the largest distance from the point to any observation within the local neighborhood. A maintained assumption is that the regression surface at any point can be approximated by a simple linear function. And the flexibility is introduced by estimating a weighted linear regression point by point.

Local regression has its particular advantages in modeling urban spatial structure, as it is very flexible and capable of depicting the local relationship between the response and the predictor variable. Nonparametric analysis can help develop a better and more accurate description of urban density surfaces, while a disadvantage is that it does not produce a function that is easily represented by a mathematical formula. Therefore, the analysis is not based on specific parameters, like the density gradient in a density function, but requires visualizing the regression surface by drawing the smoothed curve or surface on a scatter diagram. Because of this other metrics will be needed beyond estimated gradient values in order to characterize changes in the spatial distribution of population.

2.3.2 *Identifying population subcenters*

A population subcenter is defined as an area with significantly higher population density than nearby locations, which has a significant effect on the overall population distribution in the metropolitan area. Therefore, the nonparametric identification of population subcenters involves two steps (McMillen, 2001). The first step is to identify candidate subcenters as significant positive residuals in a smoothed loess density surface. Local regression is applicable to surface fitting. A population density surface can be expressed as

$$D = f(x, y) \tag{3}$$

where x is latitude; y is longitude; D is the density at (x, y); and f is a regression function. The density surface is formed by fitted values at each point on a grid overlaying the sample area. To reduce the computational complexity, we get the surface using interpolated fitting, which means local regression is only performed at a representative sample of points in the predictor space and the regression surface is obtained by blending these local polynomials. The smoothing parameter is selected using the same procedure as above.

The loess surface serves as a benchmark, and subcenters have densities that greatly exceed the loess smooth. So candidate subcenters consist of tracts with residuals that are significantly greater than 0 at the 5% significance level. To avoid taking nearby tracts as different potential subcenters, we only choose those whose predicted densities are highest in a cluster of nearby tracts with significant residuals as candidate subcenters, where 'nearby' is defined as within a radius of 4 km.

The second step is to apply a semiparametric procedure to assess the significance of the candidate subcenters. Only those that have significant impacts on the overall distribution of population can be identified as effective subcenters. The semiparametric regression is given by

$$D_i = g(x_i) + \sum_{j=1}^{n}(\delta_{1j}x^{-1}_{ij} + \delta_{2j}x_{ij}) \tag{4}$$

where D_i denotes the density at tract i; x_i denotes the distance from tract i to the city center; x_{ij} denotes the distance between tract i and candidate subcenter j; δ_{1j} and δ_{2j} are the coefficients of the subcenter distance variables to be estimated; and n is the number of candidate subcenters. x_i enters the equation nonparametrically, and McMillen (2001) suggested various alternatives can be used to estimate $g(x_i)$. We apply cubic splines to approximate $g(x_i)$ as used by Anderson (1982, 1985), written as

$$g(x_i) \approx a + b(x_i - x_0) + c(x_i - x_0)^2 + d_1(x_i - x_0)^3 + \sum_{k=1}^{n-1}(d_{k+1} - d_k)(x_i - x_k)^3 Y_k \tag{5}$$

where x_k ($x_k < x_{k+1}$, k = 1, 2, …, $n-1$) are the knots dividing the distance interval from the city center to the metropolitan area boundary into n segments; a, b, c and d are the regression coefficients to be estimated; and Y_k is a dummy variable such that

$$\begin{cases} Y_k = 1 & \text{if } x_i \geq x_k \\ Y_k = 0 & \text{if } x_i < x_k \end{cases} \tag{6}$$

The number of knots is not supposed to be large. Though increasing the number of knots gives the spline more freedom to bend, it also increases the number of parameters to be estimated. Therefore, we choose three knots at distance 20 km, 40 km and 60 km from the city center respectively. To assess the significance of the candidate subcenters, the hypothesis tests on the coefficients of δ_{1j} and δ_{2j} are conducted. One problem with this approach is regarding the severe multicollinearity produced by multiple distance variables entered into the regression. McMillen (2001) suggested a reverse stepwise regression procedure to choose the number of subcenter distance variables. The procedure starts with the equation with all distance variables entered. At each iteration step, the subcenter distance variable with the lowest t value is eliminated until all subcenter variables in the regression are significant at the 5% significance level. The intercept and cubic splines are forced to remain at each stage. The final list of subcenters includes those whose coefficients have expected signs on either x_{ij} or x^{-1}_{ij} (or both) at the end of the stepwise regression.

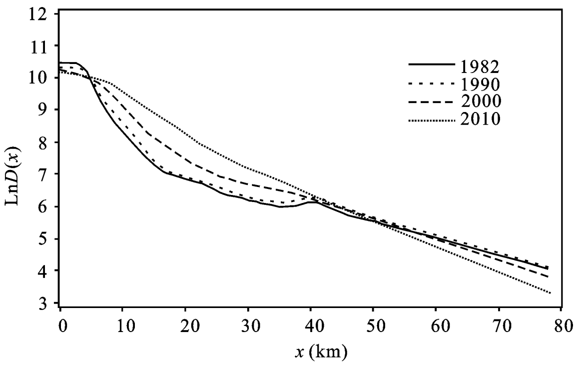
3 Results and Analyses

3.1 Evolution of population density patterns

To characterize the population density pattern using local regression, we still use the classic negative exponential density function, which serves as a base specification for the local regression:

$$\ln D(x_i) = \ln D_0 + \beta x_i \tag{7}$$

where $D(x_i)$ denotes the gross population density at distance x_i from the city center; D_0 is the density extrapolated to distance zero; β is the density gradient to be estimated. Compared with linear or nonlinear least squares regression, local regression adapts locally to curvature in the regression surface that is not accounted for adequately by the base equation, and estimates the regression surface more accurately (McMillen and McDonald, 1997). Figure 2 shows the local regression fit lines. The smoothing parameter is selected to minimize the bias-corrected *AIC* criterion. The parameter value is 0.23 for 1982 and 1990, 0.39 for 2000, and 0.42 for 2010, which means there are 38, 47, 91 and 101 points included in the local neighborhood respectively for the four years.



$D(x_i)$ denotes gross population density at distance x_i from the city center; x_i denotes distance from tract *i* to city center (km)

Fig. 2 Loess fit of logarithmic negative exponential density function

The local regression fit lines represent the growth pattern of population densities in the Beijing metropolitan area since 1982. The smooth curves capture the density crater at the city center, and indicate the decline in density over time in the central area near the center. During the 1980s, all densities at the places beyond 5 km from the center have risen slightly, indicating the spread of population out of the inner city, while from 1990 to 2000, substantial growth of population mainly occurred in the areas beyond 5 km but within 40 km from the center, and densities at the places beyond 40 km from the center have decreased in general, which indicates the concentration of population into the near suburbs from both the inner city and the outer suburbs. This trend has continued after 2000. From 2000 to 2010, population densities at the places beyond 5 km but within 40 km from the center kept growing, while densities near the center were stable and densities at the places beyond 40 km from the center kept decreasing. This indicated the continuous decentralization and reconcentration of population from the city center to the near suburbs.

The results indicate that the population has decentralized in the Beijing metropolitan area during the decades, as there is clear evidence that people have moved away from the inner city, but the spatial extent of decentralization is limited in general. Instead of spreading throughout the whole metropolitan area, the population has been decentralized mostly within the urban area, from the inner city to the near suburbs. Meanwhile, the rapid growth of population in the near suburbs has significantly expanded the spatial extent of the central city, making a larger agglomeration of population within the urban area. From this point of view, the tendency toward decentralization at the level of the metropolitan area is questionable, as people have become more concentrated within the urban area, instead of further dispersing to the outer suburbs.

3.2 Population subcenters and spatial restructuring of population

Empirical studies on the evolution of metropolitan areas in western countries, especially in the United States, have indicated the evolving of large decentralized metropolitan areas towards polycentric urban forms with subcenters emerging in the suburbs and making their marks on urban spatial structure (Anas *et al*., 1998). But less evidence has been presented for metropolitan areas in developing countries. In this section, we investigate the structural change of the Beijing metropolitan area from 1982 to 2010 with the decentralization of population.

We identify the population subcenters in the Beijing metropolitan area in 1982, 1990, 2000 and 2010. First, local regression has been used to fit the population density surface. The smoothing parameter is selected to minimize the bias-corrected *AIC* criterion, and the parameter value is around 0.10 for 1982, 1990 and 2000, and 0.16 for 2010. Secondly, the semiparametric regression has been used to assess the significance of candidate subcenters. Table 2 reports the final list of subcenters identified. Our findings support the statement of Wang and Zhou (1999) that subcenters have started to emerge in the suburbs since the 1980s. We find an in-

Table 2 Final list of population subcenters and estimation results

Subcenter ID	Distance variable	1982		1990		2000		2010	
		Estimate	*P* value	Estimate	*P* value	Estimate	*P* value	Estimate	*P* value
1	x_{ij}	–0.021	0.018						
	x^{-1}_{ij}								
2	x_{ij}								
	x^{-1}_{ij}	3.851	0.0002	7.175	<0.0001	4.363	<0.0001	4.159	0.007
3	x_{ij}			–0.045	0.009				
	x^{-1}_{ij}	1.371	0.042	1.651	0.028				
4	x_{ij}			–0.084	0.001				
	x^{-1}_{ij}					2.263	0.014	9.371	0.008
5	x_{ij}			–0.324	<0.0001				
	x^{-1}_{ij}								
6	x_{ij}							–0.237	0.001
	x^{-1}_{ij}								
7	x_{ij}							–0.489	0.001
	x^{-1}_{ij}								
8	x_{ij}								
	x^{-1}_{ij}							3.846	0.033
9	x_{ij}								
	x^{-1}_{ij}							7.730	0.003
10	x_{ij}								
	x^{-1}_{ij}			6.708	<0.0001	8.605	<0.0001	4.325	0.042
11	x_{ij}					–0.194	<0.0001	–0.421	<0.0001
	x^{-1}_{ij}								
12	x_{ij}								
	x^{-1}_{ij}							8.596	0.001
13	x_{ij}					–0.023	0.072	–0.105	<0.0001
	x^{-1}_{ij}					5.362	<0.0001		
14	x_{ij}					–0.326	<0.0001		
	x^{-1}_{ij}							5.271	0.007
15	x_{ij}							–0.215	0.0002
	x^{-1}_{ij}								
16	x_{ij}								
	x^{-1}_{ij}					8.034	<0.0001	8.041	<0.0001
Adjusted R^2		0.899		0.901		0.908		0.919	

Notes: x_{ij} denotes the distance between tract *i* and candidate subcenter *j*; subcenter ID: 1. Donggaodi (Fengtai); 2. Jinding (Shijingshan); 3. Zhongguancun (Haidian); 4. Guanzhuang-Sanjianfang (Chaoyang); 5. Yongdinglu (Haidian); 6. Bajiao (Shijingshan); 7. Tuanjiehu (Chaoyang); 8. Wangjing (Chaoyang); 9. Huilongguan (Changping); 10. Yingfeng (Fangshan); 11. Xingcheng (Fangshan); 12. Gongchen (Fangshan); 13. Shengli-Shiyuan (Shunyi); 14. Beiyuan (Tongzhou); 15. Zhongcang (Tongzhou); 16. Chengbei (Changping)

creasing number of subcenters emerging through the years, with 3 subcenters in 1982, 5 subcenters in 1990, 7 subcenters in 2000 and 13 subcenters in 2010. The adjusted R^2 of the semiparametric regression gets higher in the later years, which suggests a better fit of the polycentric model for the Beijing metropolitan area in more recent times.

Figure 3 depicts the location of the subcenters and shows the evolvement of subcenters during the three decades. In 1982 and 1990, most of the subcenters were located in the near suburbs within the urban area. Though subcenters started to emerge in the outer suburbs in 1990, most of the outer suburban centers formed after 1990. In 1982, three subcenters formed in the western, northwestern and southern inner suburbs, with the central agglomeration mainly contained within the second ring road. From 1982 to 1990, the central agglomeration expanded not so much, only slightly to the northeast. The newly emerged subcenters in 1990 were mostly in the western and eastern inner suburbs and along the east-west axis. From 1990 to 2000, the central agglomeration expanded more significantly, especially to the north, experiencing the process of conurbation, and the subcenters in the west and northwest near the central area have been combined within the central agglomeration and their effects on population distribution were not significant any more in 2000. The newly emerged subcenters in 2000 were all located in the outer suburbs, with subcenters distributed throughout the metropolitan area. From 2000 to 2010, the central agglomeration expanded further and more rapidly, and its spatial extent has reached to the fifth ring road, which shows the continuous decentralization of population in the urban area of Beijing. Meanwhile, the number of population subcenters increased greatly from 7 to 13, indicating a more dispersed and polycentric spatial structure of population distribution in the Beijing metropolitan area. The newly emerged subcenters in 2010 were mainly located in the large scale residential development areas in the near suburbs (Wang jing, Hui long guan) as well as in the new towns of the outer suburbs.

4 Discussion

Generally speaking, the existence of the subcenters is persistent over time because of the historical pathdependence of the city's development. However, considering the continuous growth of the central agglom-

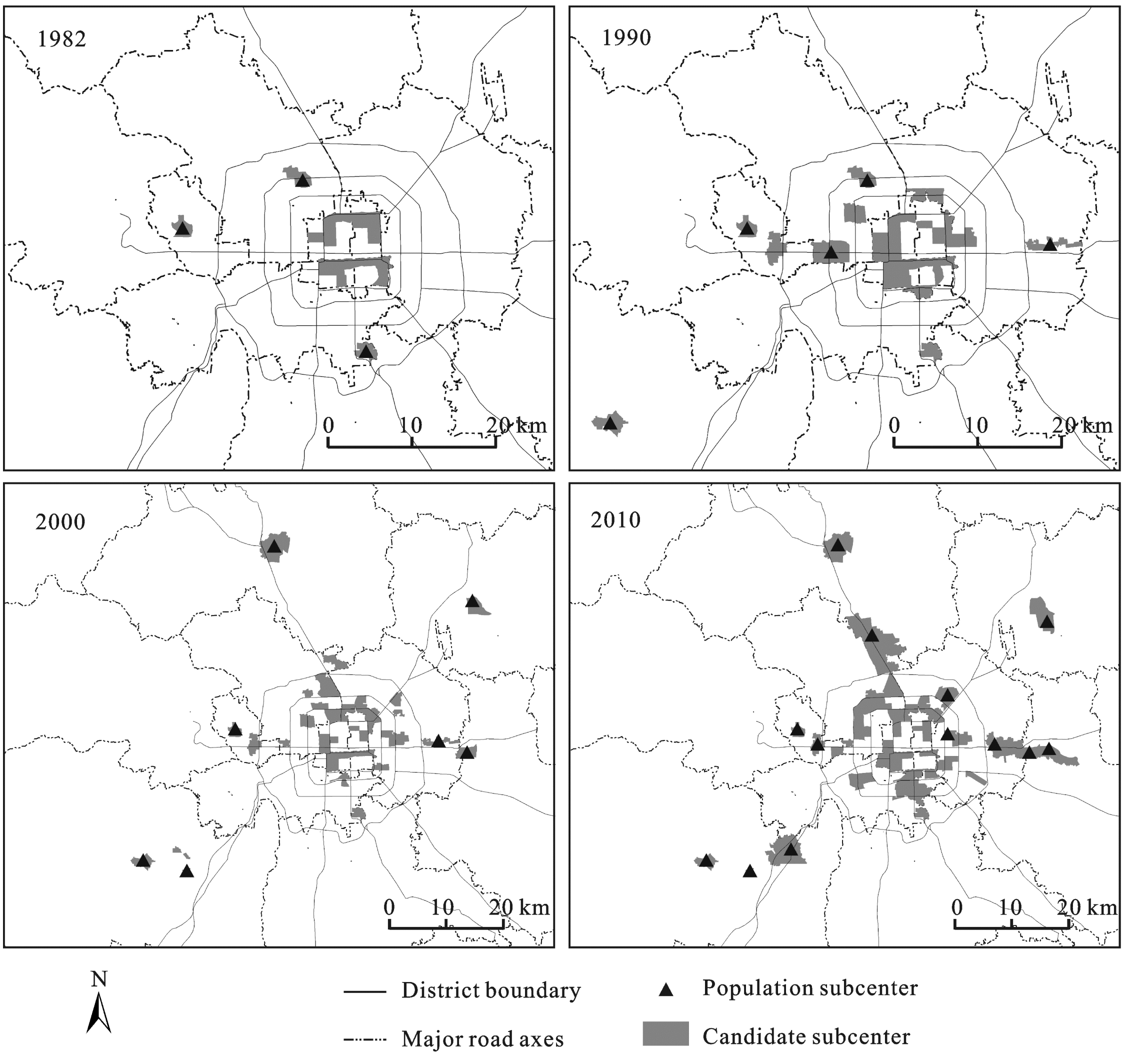


Fig. 3 Location of subcenters and expansion of central agglomeration of population

eration, nearby subcenters may form first and then be incorporated into it later. From this point of view, the central agglomeration may not be monocentric by nature, and it may also have a polycentric structure. Meanwhile, the influence of the road system is clear, with all the subcenters organized around the ring roads or along the transport axes. Several subcenters along the east-west axis are close together and can be considered as a group that forms a corridor extending from the central area all the way to the western and eastern near suburbs.

The emergence and development of population subcenters and the urban spatial restructuring in terms of the population distribution that happened in the Beijing metropolitan area during the post-reform era need be understood with reference to the changing urban development process in the post-reform China. Wu and Yeh (1999) argued that the decentralization policies and the marketization of urban land-use rights and housing that started in the mid-1980s have fundamentally changed the organization of urban development in China. Before the reforms, urban development in China followed the project development scheme of the centrally-planned economy, with state enterprises rather than local municipalities as the main actors in the organization of urban development. In such a system, state enterprises provided services, facilities and housing to their employees, and therefore they directly organized the development of housing, facilities and even infrastructure. The predominant role of state enterprises in urban development was evident in the development of Beijing in the early years of the reforms. For example, the subcenter 2 (Jin ding) and 10 (Ying feng) in the western and southwestern suburbs of Beijing emerged in 1982 and 1990 respectively are just attributed to two of the largest state enterprises in Beijing: the Capital Iron and Steel and the SINOPEC (China Petroleum and Chemical Corporation) Beijing Yanshan Petrochemical.

After the reforms, the decentralization has localized the urban development process and strengthened the status of local municipalities in urban development and management. The role of state enterprises has been weakened. The municipality began to play a more active role in urban development through city-wide comprehensive development and manage urban development using urban planning. Planning then plays a key role in the development of post-reform Chinese cities. To strictly control the scale of the central city, the planning authority of Beijing has made the plan to maintain a scattering layout of the city back in the 1950s. In the 1982 master plan, following this scattering layout principle, several satellite towns have been planned to be developed in the outer suburbs since the 1980s, aimed at attracting population and industries, to avoid the undesirable sprawl of the central city. Besides, 10 scattered residential groups were also planned as inner suburban development areas at the edge of the urban area, to avoid the over concentration of population in the central city. These groups are mostly residential and have been developed through large investment in housing during the 1980s and the 1990s. After 2000, the municipal government of Beijing and its planning commission has revised the master plan, and the latest master plan of Beijing for the period 2004–2020 provided new guidelines for the development of the city, and planned a polycentric structure with two urban axes in the central city, two belts for ecological conservation and economic development respectively, and multi-centers both in the central city and throughout the metropolitan area. Figure 3 shows that the development of the subcenters in the Beijing metropolitan area is highly associated with the development scheme of the city. The subcenters are mostly located in or around these edge development areas if they are within the urban area, while the outer suburban centers are all located in the satellite towns or new towns.

Another factor that contributed to the suburban growth and the emergence of the suburban subcenters was the massive influx of rural migrants. The migrants were mostly concentrated in the periphery of the urban area, where they were easily accessible to jobs and the housing rent was generally low. As a result, concentrated areas of rural migrants have made a specific form of suburban subcenters, also known as migrant enclaves, such as the subcenter 1 (Dong gao di) in the Beijing metropolitan area.

The polycentricity emerged in the Beijing metropolitan area is very different by nature from that observed in western cities. Clark and Kuijpers-Linde (1994) summarized two different models of polycentricity when studying two prototype regions of polycentric structures, i.e. the Randstad and Southern California: the market-driven polycentricity portrayed as one of emerging urban centers with shifts in the hierarchy of centers, and the history-based polycentricity portrayed as one of a collection of separated urban centers in which locality and history play an important role. Clearly, the polycentricity emerged in Beijing is different from the both models and has different origins. The structure was initially driven by the planning efforts to promote dispersed and scattering metropolitan development and the designation of numerous edge development areas and satellite towns. The subcenters emerged are adherent to the development scheme planned for the city, so it can be referred to as the so called ′planned polycentricity′.

5 Conclusions

The objective of this study is to understand better the population distribution and its evolution in the Beijing metropolitan area during the post-reform era. Our findings suggest similar trends and patterns for the Beijing metropolitan area to those observed in large Western cities. The population has spread with rapid urban growth, and the compact urban form has been replaced by a more dispersed polycentric spatial distribution. However, compared with the decentralization of the cities in western countries, the spatial extent of the decentralization of population in the Beijing metropolitan area is quite limited. We find people have moved out of the inner city, but concentrated in the near suburbs, instead of dispersing throughout the metropolitan area. The rapid growth of population in the near suburbs has expedited the sprawl of the central city, with a larger central agglomeration of population dominating the metropolitan area. In this sense, the spatial pattern of the Beijing metropolitan area is still characterized by the continuous compactness. This is also endorsed by the fairly good fit of the monocentric density function applied to modeling the density patterns in the Beijing metropolitan area in previous studies. Although most scholars still regard Beijing as a monocentric city, our findings provide the evidence that the city has been turning to a polycentric structure in terms of the population distribution. We find significant population subcenters have emerged in the suburbs of Beijing since the 1980s, and the number of subcenters in the Beijing metropolitan area has kept increasing, which indicates the spatial structure has been polycentrified.

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