POSTSUBURBAN SPATIAL EVOLUTION OF VIENNA'S URBAN FRINGE: EVIDENCE FROM POINT PROCESS MODELING[1]

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Abstract: Metropolitan areas today are faced with pervasive changes of their urban spatial structure and are reshaped by postsuburbanization processes. In this study, one example of such postsuburban restructuring, the multinucleated monofunctional clustering of higher-order services, is investigated in the urban fringe of Vienna, Austria. The methodological framework uses microgeographic data for 2006 and applies a case-control point process modeling approach, which accounts for nonstationarity in first-order effects. The results show a relocation of highly specialized firms into the outer metropolitan ring, where these firms provide functional enrichment. This disagrees with the classical notion of a central place hierarchy. The urban fringe thus increasingly conforms to the core city. This spatial functional agglomeration shows statistically significant evidence of a bicentric urban structure, with the two new subcenters located in traditional suburban areas. Accordingly, Vienna's urban fringe is being altered by new postsuburban forms. [Key words: suburbanization, postsuburbanization, polycentric urban structure, point pattern analysis, Vienna.]

THE EVOLUTION OF SUBURBAN SPACE

For decades, urban spatial structures have been an important research topic in various disciplines, including geography, economics, and planning. The reason is that spatial patterns of cities are continuously being reshaped by various endogenous and exogenous forces. In addition, the more recent impacts of globalization, the shift to an information economy, new communication technologies, deregulation, and social and demographic changes have profoundly changed metropolitan forms (Castells, 1989; Hall, 1993; Anas et al., 1998).

These new developments have transformed the spatial structure of the urban fringe, as well as the core city. Urban fringes were primarily shaped by suburbanization processes, which resulted in an intraregional deconcentration of people, retail activities, and

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industrial facilities (Friedrichs and Rohr, 1975). Nevertheless, the core city still remained the most important part of the metropolis for employment, international activities, commuting patterns, and higher-order services. Thus the outer ring continued to be functionally dependent on the core city (Glaeser and Kahn, 2004). This has been described using various forms of monocentric urban models (Clark, 2000). Examples include the land rent model (Alonso, 1964) and the social–ecological concentric-ring model of land use (Park et al., 1925), which both assume that urban geographic space is isotropic, homogenous, and lacking in agglomerative effects (Anas et al., 1998).

However, these models are no longer valid for exploring evolving urban patterns in advanced economies such as those of Europe or the United States (Kloosterman and Musterd, 2001). At present, myriad metropolitan areas are undergoing an evolution from a monocentric to a polycentric structuring, which is documented in recent research (Getis, 1983; Dieleman and Faludi, 1998; McMillen and McDonald, 1998; Hall, 1999; Kloosterman and Lambregts, 2001). Today, many metropolitan regions in advanced economies possess several spatially separated centers consisting of large populations and employment clusters (Parr, 2004).[3] Because of this new intrametropolitan structure, Anas et al. (1998), Clark (2000), and others have proposed a reformulation of traditional models and conceptualizations of urban form. More recent research (Gordon and Richardson, 1996; Lang, 2003) goes even further and interprets the current restructuring of the metropolis as having already moved beyond a polycentric pattern.

Because a "grand theory" of polycentricity is still lacking (Kloosterman and Musterd, 2001, p. 624), urban geographers are increasingly interested in this research arena and have begun to integrate polycentric patterns into their explanations of metropolitan morphology. There is also an ongoing debate about postmodern change in the structuring of metropolitan areas toward something "new" that goes beyond the more traditional suburban perceptions of Fishman (1987), Garreau (1992), Kling et al. (1995), Sieverts (1998), Soja (2000), Lang (2003), and Brake (2005). So far, no common agreement exists in the literature as to how to label this new spatial structure. The literature refers to this new structure in several metaphoric terms, which describe (nearly) the same spatial phenomenon yet focus on different characteristics.

The most often mentioned terms are "edge city" (Garreau, 1992), "postsuburbia" (Kling et al., 1995), "in-between-city" (Sieverts, 1998), "exopolis" (Soja, 2000), and "edgeless cities" (Lang, 2003). All these labels have two things in common: they refer to a postmodern urban society (Dear and Flusty, 2002) and highlight a certain "maturing" of suburban structure, the latter providing both functional enrichment and a spatial reorganization that benefits suburban economic development.

In order to avoid terminological uncertainties, the process driving this new spatial structure will henceforth be called postsuburbanization. The new spatial structure itself will be labeled Postsuburbia. This terminology seems appropriate because it includes various development trends such as the agglomeration of offices and retail space in the urban fringe, and the diversity of the population and multinucleated structuring in the more immediate surroundings of the core city.

[3]For a definition of a polycentric urban region, see Parr (2004, pp. 232–233).

One characteristic of the postsuburban landscape is the fragmentation of the metropolis into independent residential, economic, social, and cultural zones (Wood, 2003). Thus postsuburban spatial patterns are also based on polynucleated structures located in urban fringe. Polynucleated structures are nothing new or unique and have been created by firms relocating from the core city to the periphery over the past few decades. Among those firms are lifestyle and health services, which have resulted in a functional enrichment of the outer ring (in contrast to the prescriptions of central place theory). Moreover, these relocating services impact the structure of the population, which becomes more diverse both in demographic and socioeconomic terms (Brake, 2005).

Because of the increased importance of agglomeration economies and in order to maximize profits, services maximize spatial proximity by clustering (Soja, 2001). This results in a polynucleated, monofunctional urban structure in the outer ring (Kunzmann, 2001). A further consequence of this functionally enriched polycentric pattern is the emancipation of the urban fringe from the core city. Thus the traditional core city is losing its intra-metropolitan primacy and becomes just one of the many components of the urban region (Fishman, 1987; Brake, 2005). As one may expect, this has an important spatial consequences as well. One is that suburban commuting, which traditionally was dominated by radial movement to and from the core city, is now characterized by less defined and multidirectional work-trip patterns (Schwanen et al., 2001).

Although spatial changes associated with postsuburbanization are theoretically and conceptually established, empirical verification is largely lacking. Therefore, the purpose of this investigation is to provide an empirical evaluation of these "postsuburban theories" using the urban fringe of Vienna as a laboratory. Because of the complexity of these urban developments, which incorporate economic, social, and demographic dimensions, this research primarily focuses on one aspect of postsuburban spatial structuring: analysis of the changing distribution of service-sector locations. Using a point process modeling framework, the aim is to uncover the degree of clustering of a variety of highly specialized (*postsuburban*) services and evaluate their spatial associations. Because of spatial heterogeneity in the location of services, the use of a case-control design is necessary.

Two key research questions are posed: Is there empirical evidence that a monofunctional, polynucleated urban structure exists in Vienna's urban fringe? And is there evidence that the locations of postsuburban services are more clustered than the locations of other service-sector firms? This study is organized as follows. The next section reviews the literature on urban spatial structures and summarizes findings that are relevant to the context of this investigation. Next, the study site and data are introduced. The subsequent section presents a brief overview of the methodology to estimate first- and second-order effects. Based on the previous section, results of the empirical analysis are discussed. The concluding section summarizes and relates the findings to the body of postsuburban theory and contemplates future research questions.

METHODOLOGICAL ISSUES AND EMPIRICAL EVIDENCE OF POSTSUBURBAN FORMS

The transformation of metropolitan areas from monocentric to polycentric structures been examined primarily for the United States (e.g., McMillen, 1996) and selected European cities (e.g., Dieleman and Faludi, 1998). Because so many different techniques have been used to evaluate local spatial variability, this complicates the comparison of empirical findings (Kloosterman and Musterd, 2001). To date, methods to discover polycentric patterns or service location clustering include differential density functions (McMillen, 1996), fractal models (Keersmaecker et al., 2003), autocorrelation statistics (Baumont et al., 2004), and point pattern analysis (Getis, 1983).

Point pattern analysis has already been used successfully to analyze industrial location patterns (Barff, 1987; Feser and Sweeney, 2000; Duranton and Overman, 2008). More than two decades ago, Barff (1987) analyzed manufacturing plants in Cincinnati, but did not account for first-order spatial variations in the point pattern. Accounting for such spatial variations by using a case-control design, Feser and Sweeney (2000) showed that an association between economic linkages and geographic clustering occurs in North Carolina—specifically the clustering of firms in the knowledge-based or technology-intensive sectors. Maoh and Kanaroglou (2007) subsequently tied economic clustering to urban form by using spatial statistical techniques such as the $K(d)$-function and simultaneous auto-regressive models. For the city of Hamilton (Canada) they found some evidence for decentralization tendencies in population and firms, and concluded that a multinucleated urban form would be likely to emerge. Finally, Cuthbert and Anderson (2002) demonstrated the power of such point pattern methodologies in their spatiotemporal analysis of the Halifax–Dartmouth metropolis in Atlantic Canada. Their results pointed to a changing urban form and they considered multinucleation a possibility.

Numerous other case studies have already verified the hypothesis of polycentric urban patterns. This is true in the United States for the metropolitan areas of Atlanta (Hartshorn and Muller, 1989), Dallas–Fort Worth (Shukla and Waddell, 1991), and Houston (Craig and Ng, 2001). In Europe, polycentric urban patterns have been validated for the Rhine–Ruhr megalopolis (Blotevogel, 1998), the Dutch Randstad (Dieleman and Faludi, 1998), and Greater Munich (Kagermeier et al., 2001), among others.

Comprehensive studies of Chicagoland have proven that the monocentric metropolis pattern ceased to exist in the 1960s (McMillen, 1996). One such study was conducted by McMillen and McDonald (1998) on the distribution of employment; of the 20 suburban subcenters they analyzed, three were explicitly classified as edge cities, with these multifunctional concentrations of offices, retail, entertainment, and housing areas located at a considerable distance from the Loop. Another study by McDonald and Prather (1994) supported those results. Contrary to these two examples, which primarily used a suite of density functions like nonparametric locally weighted regression, Getis (1983) used second-order point pattern methodology to explore the multicentric hypothesis for population in the Chicago region. He concluded that Chicago had more than one center of high population density, a pattern hardly unique to Chicago. Several other scholars, notably Kling et al. (1995), Fishman (1987), and Soja (2000) agree that the Los Angeles metropolitan area is the prototype of the postsuburban landscape.

Therefore, it is not surprising that many of the subsequent empirical studies emphasized Los Angeles as the leading example of polycentric urban form, even though Gordon and Richardson (1996) claimed that Los Angeles had already matured from a polycentric to a more fully dispersed metropolis. Lang (2003) echoed that perception and introduced the more diffuse concept of "edgeless cities," a kind of scattered development across the post suburban landscape that never obtained the scale, density, and cohesiveness of edge cities. Empirical findings for other metropolitan areas, such as Miami and Philadelphia, further supported this hypothesis (Lang, 2003; Lang et al., 2009). Using employment data for 1980–2000 and indices of centralization and concentration, Lee (2007) also confirmed continuing decentralization tendencies for Portland, Oregon, and Philadelphia, Pennsylvania. He drew the additional conclusion that the transition from a monocentric to a polycentric to a dispersed pattern is not a general, linear process, but rather locally diverse.

Borsdorf (2003), however, showed that the resulting urban pattern was not necessarily homogeneous, but closer to that of a fractal structure. Analyses of fractal geometries had already been conducted for certain European metropolises, including Brussels, Belgium (Keersmaecker et al., 2003), and Dresden, Germany (Thinh, 2003); the results for Dresden revealed a morphology approaching this fractal structure, while increasing in complexity over time. A further (and fairly simple) approach was conducted by Bontje and Burdack (2005), who used a standard descriptive research design to evaluate the possible occurrence of edge cities in European metropolitan areas such as Paris and the Netherlands' Randstad. They concluded that "city-edges" are the European counterparts to the North American edge cities. Nonetheless, city-edges have only limited similarity to edge cities in the range of specialization (e.g., financial and insurance institutions) and they are not yet spatially independent of the core city. Consequently, city-edges cause no economic decline of core cities. For instance, Rohr-Zänker (1996) and Anas et al. (1998) agreed with Bontje and Burdack (2005) in comparing German cities to those in the United States. Studies by Dieleman and Faludi (1998) and Kloosterman and Lambregts (2001) also defined the Randstad region as a polycentric urban pattern. But Batty (2001) rejected the notion of polynucleation and the rise of edge cities: using spatially disaggregated models of urban development, he argued that such multicentered metropolitan landscapes result from temporal evolution of the initial, random distributions of urban activities.

A few studies refute the existence of the polycentric urban region. One by Baumont et al. (2004) analyzed the spatial distribution of population and employment in metropolitan Dijon (France) using autocorrelation statistics and Bayesian techniques. The authors concluded that the spatial pattern still exhibited a monocentric character. Also, Riguelle et al. (2007) concluded that for Belgian cities, including Brussels, spatial patterns of polycentrism were still weak.

STUDY AREA AND DATA

Study Area

The study area for this research is Vienna's urban fringe (Fig. 1). Several concepts exist to delineate metropolitan Vienna. We will employ a slightly modified boundary for this metropolitan area from Fuchs (1997) in that the core city is excluded because the urban structure outside the traditional core has already matured and broken away. Thus the city center has become marginalized, since it is only one of many nuclei within the metropolis (Fishman, 1987; Brake, 2005). This also holds true for the structure of postsuburban landscapes wherein monofunctional clusters are only located in the immediate surroundings of the core city.

Vienna's urban fringe has experienced growth in its residential population since the 1960s, with an upsurge after 1980 owing to an influx from Vienna as well as from rural

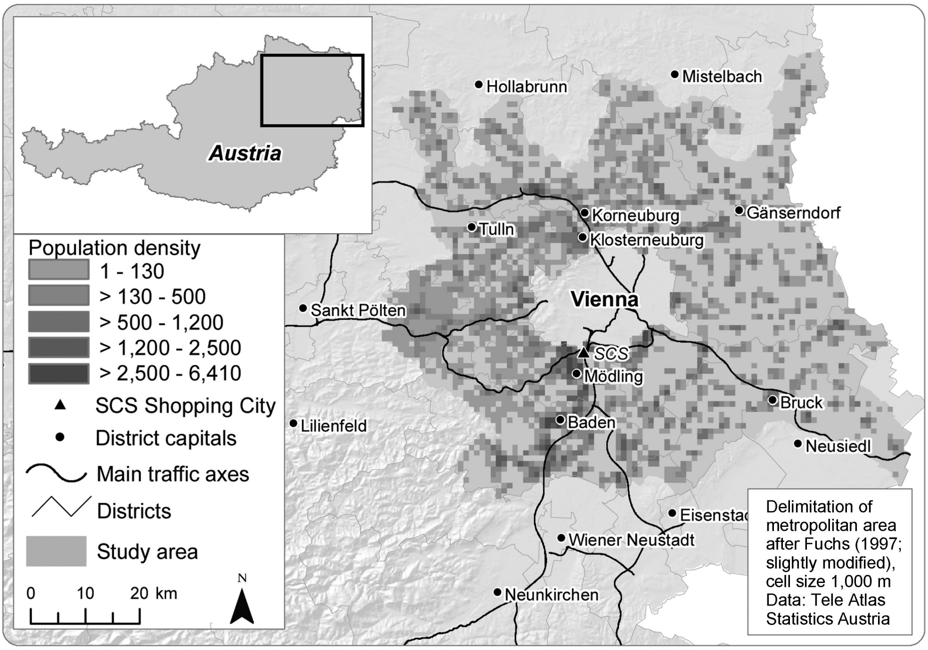

Fig. 1. Population density in Vienna's urban fringe, 2001.

districts adjacent to the metropolis. The residential population of the study area increased from 517,000 to about 615,000 inhabitants between 1981 and 2001, which amounts to a 19% increase. Figure 1 shows the study area in 2001. Overall, population densities increase from east to west, and the fastest-growing localities are found in the northern suburbs as well as along the main traffic axes south of Vienna.

Data and Data Preparations

To evaluate polynucleated urban structures in the study area, geocoded locations of service-sector firms in April 2006 are used. The microgeographic data for this research were primarily collected from Herold Business Data, and are distributed by WiGeoGIS, a private data provider in Austria (http://www.herold.at/en/; http://www.wigeogis.com). Herold publishes the "Marketing CD Business Geo," which contains highly accurate geo-referenced firm locations and associated attributes (e.g., industrial classification code, business volume). In terms of accuracy, 49.1% of all locations have a street-number accuracy of approximately 10 m and 47.6% have a block accuracy of about 100 m (the remaining 3.3% have a lower positional accuracy).

In this study, the aggregation of services into supergroups of postsuburban services is based on Kunzmann (2001). He argues that today's metropolitan areas consist of several monofunctional clusters of firms, one of which is called "www Suburbia" and includes such postsuburban services as software development, computer networks, and data processing

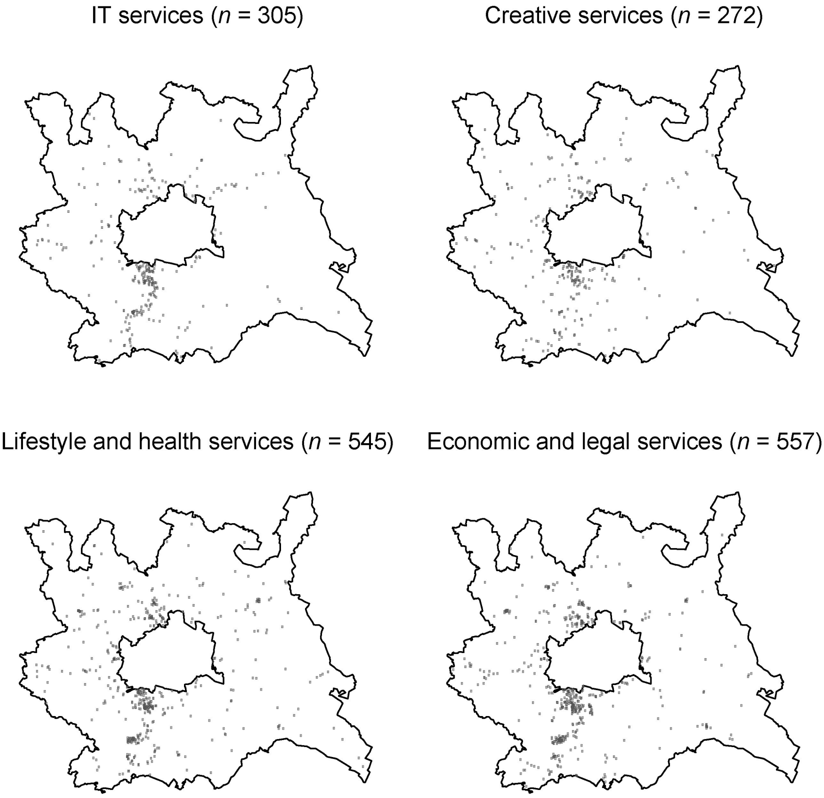

Fig. 2. Spatial point distributions of four postsuburban service groups for 2006. Each point represents one service location.

services. Four of Kunzmann's supergroups are used here, and they consist of the following economic activities:[4]

(1) *IT services*—Software, software development, Internet, data processing, computer repair and service, computer networks, computer peripherals, Internet service providers, etc.

(2) *Creative services*—advertising agencies, advertising art and design, graphic design, web design, multimedia, etc.

(3) *Lifestyle and health services*—psychotherapists, psychologists, nutritional advisors, biological products, alternative therapies, coaching and mediation, kinesiologists, etc.

(4) *Economic and legal services*—management consultants, chartered accountants, investment advisors, public relations, financial advice and business management consultants, marketing, management consultants, etc. The spatial distribution of the supergroups is mapped in Figure 2.

[4]Because of the absence of additional attribute information (e.g., size of firms, number of employees) small and large firms are treated identically. This could induce some bias.

RESEARCH METHODOLOGY

Point Patterns and Processes

A number of spatial statistical methods are available to study metropolitan form, and a point pattern methodology is used here to test whether or not a multinucleated urban pattern exists. One important advantage of using disaggregated microgeographic data and their associated methods is the freedom from the "tyranny" of zones. In other words, the spatial aggregation bias and the modifiable areal unit problem (Openshaw, 1984) are not an issue. Previous analyses have shown that point pattern modeling techniques are useful to test hypotheses of agglomeration.

The general purpose of point pattern analysis is to explain the empirical spatial distribution of a set of points with statistical models in order to measure the consistency of a theoretical pattern and to make inferences about the underlying spatial point process (Getis and Boots, 1978). A spatial point process is a stochastic mechanism that generates a set of points s ($s = s_i$, s_j) in an area A (Diggle, 2003). The simplest kind is the commonly used homogenous Poisson process, where the arrangements of points show complete spatial randomness (Bailey and Gatrell, 1996). Because this process assumes a uniform distribution and no interaction between the points, it is rarely appropriate for geographical applications (Fischer et al., 2001).

Commonly, point processes are characterized by their first two moment measures. The first-order effects, the density λ, simply describe the variation of the expected value across space. Second-order effects measure the covariance between two points i and j (Bailey and Gatrell, 1996). Usually, first-order effects can be addressed by a kernel smoothing estimator and second-order effects by the $K(d)$-function (Ripley, 1976). The following two subsections discuss both effects in more detail.

Estimating First-Order Effects

Kernel density estimation transforms the discrete point pattern into a continuous smoothed surface consisting of local density estimates $\hat{\lambda}(x)$ (Waller and Gotway, 2004). A quartic kernel function (Rowlingson and Diggle, 1993)

$$f(x) = \begin{cases} \left(1 - \frac{u^2}{2}\right)^2 & -\sqrt{2} \le u \le \sqrt{2} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

that weights the points according to a given distance, moves from cell i to j on a superimposed grid. The sum of these individual kernel estimations

$$\hat{\lambda}(x) = h_0^{-1} \sum_{i=1}^{n} f\left(\frac{d_i}{h_0}\right) \tag{2}$$

measured on the grid is the resulting local density estimation, where d_i is the distance from point i to cell x and h_o specifies the bandwidth of the kernel. This bandwidth determines the size of the kernel and the level of smoothing. The literature is inconsistent in regard to the selection of an optimal bandwidth. For instance, Bailey and Gatrell (1996) recommend trying different bandwidths, while others like Berman and Diggle (1989) suggest minimizing the mean square error to obtain an optimal bandwidth. Nevertheless, using the kernel density estimation makes it possible to measure the point distribution and explore spatial variations in their densities. This is an essential step because the $K(d)$-function that was used in this study assumes stationarity over space and potentially leads to biased results in heterogeneous environments.

Estimating Second-Order Effects in a Heterogeneous Environment

A common approach to quantifying the strength and type of interactions between the points is by applying a univariate $K(d)$-function (Ripley, 1976). It measures whether the point pattern is clustered, random, or regularly distributed across space. The advantage over the nearest-neighbor statistic is that the $K(d)$-function summarizes spatial point patterns over a wider range of distances, while assuming stationarity in the first-order effects across space (Dixon, 2002). However, most geographic processes are complex and show a heterogeneous distribution across space. For example, locational patterns of firms are often spatially clustered. Feser and Sweeny (2000) argue that firms historically have depended on resource needs and production methods. Today, their locational requirements have changed and firms locate in or near urban agglomerations. Besides this "natural" heterogeneity in the locational patterns of firms, normative planning regulations are an important second criterion. In Austria, zoning plans constrain locational decisions and determine where certain facilities are allowed to be located.

One methodological extension to account for such first-order variation is the so-called case-control design (Diggle and Chetwynd, 1991). The case-control design is operationalized by a point pattern that reflects the spatial distribution of the heterogeneous environment. It serves as a control on the other four point patterns representing the four services supergroups. The aim is thus to evaluate the spatial distribution of the four cases relative to their controls (i.e., to ascertain whether the cases are more clustered or more dispersed than the controls; Bailey and Gatrell, 1996). If no difference exists between the cases and the controls, then the cases follow a random distribution and both point patterns are produced by the same point process. In general, the univariate $K(d)$-function is defined as

$$K(d) = \lambda^{-1}\mathrm{E}\ (\text{number of points within distance } d \text{ of a randomly chosen point}) \tag{3}$$

where λ is the density (points per unit area; Ripley, 1976; Dixon, 2002). Using empirical data, the edge corrected $\hat{K}_{ii}(d)$-function for the cases can be estimated as

$$\hat{K}_{ii}(d) = \hat{\lambda}^{-1}\sum_{i}\sum_{i \neq j} w(s_i, s_j)^{-1}\frac{I(d_{ij} < d)}{N} \tag{4}$$

where $\hat{\lambda}$ is the estimated density ($\hat{\lambda} = \frac{N}{A}$, N is the observed number of points in the area A), d_{ij} is the distance between point i and j, $I(\,)$ is an indicator function, and the weight $w(\,)$ accounts for the edge correction (Dixon, 2002; Waller and Gotway, 2004). Because in a

Table 1. Number of Services in the Viennese Urban Region

	Fringe			Core city		
	Absolute	Relative (%)	Service rate	Absolute	Relative (%)	Service rate
IT services	305	21	0.51	1,142	79	0.74
Creative services	272	19	0.44	1,193	81	0.77
Lifestyle and health services	545	21	0.89	2,066	79	1.33
Economic and legal services	557	18	0.91	2,467	82	1.59

complete spatial random distribution the theoretical values of $K(d)$ follow πd^2, one can compare the estimated with the theoretical values. Under H_o, Diggle and Chetwynd (1991) showed the following relationship exists between the different $K(d)$ functions

$$K_{ii}(d) = K_{jj}(d) = K(d) \tag{5}$$

where $K_{ii}(d)$ is the $K(d)$-function for the cases and $K_{jj}(d)$ is the $K(d)$-function for the controls. Thus, the expected value of the function

$$D(d) = K_{ii}(d) - K_{jj}(d) \tag{6}$$

equals 0, which means that the case label is a random sample of the combined pattern of cases plus controls (random labeling hypotheses). Therefore, the two distributions are equally distributed over space (H_o). Departures from H_o can be used to examine differences between the two point patterns. If $\hat{D}(d)$ is plotted against a distance d, positive variations ($D > 0$) will produce clustering above that of environmental heterogeneity (controls) and negative variations ($D < 0$) indicates that the cases are more dispersed compared to the controls. Inference is carried out using simulated confidence envelopes derived from Monte Carlo tests. All calculations are accomplished in the R environment (R Development Core Team, 2008) using the SPLANCS package (Rowlingson and Diggle, 1993).

EMPIRICAL ANALYSIS

This section discusses the results of the empirical analysis using the above methodology. Similar to the residential population in Figure 1, postsuburban services are heterogeneously distributed (Fig. 2). Clearly, services locations are highly correlated with the population pattern. Both distributions are mainly concentrated in and around urban centers. Over the past few decades, postsuburban services have continuously increased in suburban Vienna (pers. comm. with the Office of the Lower Austrian Government, September 2009), thereby confirming functional enrichment in the urban fringe. But the total number of services located in the outer ring is only about one-fifth of those offered in the core city (Table 1). This rejects the notion that the core city has lost its importance because it remains the dominant services cluster in the metropolis. However, if the urban fringe and the core city are compared on a relative basis, the differential between the "service rate" (i.e., the number of services per 1000 inhabitants) is not that large (Table 1). This indicates

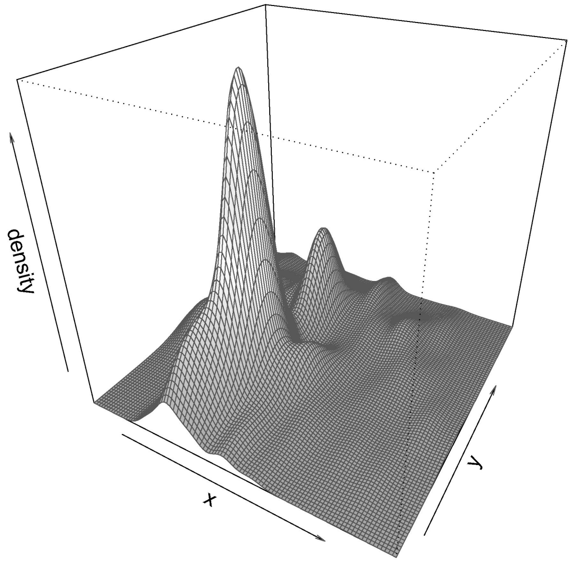

Fig. 3. Three-dimensional smoothed kernel density plot of the creative services with the bandwidth equal to 2,000 m. North is identical to the direction of the y-axis.

that the urban fringe is getting (relatively) more important as a service firm location. But do monofunctional clusters of postsuburban services already exist in the urban fringe?

A visual interpretation of the locations of the four service-sector groups clearly points to some clustering in the point patterns. To explore whether first-order effects exist across the study area, local point pattern densities are calculated using kernel estimations. A quartic kernel function with different bandwidth lengths between 2,000 m and 5,000 m was applied and visualized on a grid with a cell width of 500 m. Figure 3 illustrates the use of the kernel density estimation with a bandwidth of 2,000 m exemplified by the creative sector and showing a three-dimensional visualization of the spatially smooth estimates of the local densities. Because the plots of the other three point patterns are nearly identical and show similar shapes, they are not displayed here.

In general, the kernel density maps confirm the earlier visual impression of spatial clustering among the service-sector locations and therefore support the hypothesis of the presence of localization economies. One major hotspot is clearly visible to the south of Vienna and another northwest of Vienna (Fig. 3). Further, there is a clear trend in increasing densities from north to south. A two-dimensional display of Figure 3 (not shown here) depicts both hotspots to be clearly separated from the core city. The large hotspot in the south identifies a concentration of firm locations along the main traffic axes, particularly along the northern segment of Highway A2. This is also one of the main settlement zones in the study area, comprising completely or mostly the municipalities of Brunn am Gebirge, Maria Enzersdorf, Mödling, Wiener Neudorf, and Vösendorf. Hence, it is not surprising that firms are concentrated in this area because they are located near their customers and other firms so as to profit from spatial proximity and knowledge spillovers. Additionally, the "Shopping Center South" is located in Vösendorf and Wiener Neudorf—one of the largest in Central Europe with 226,000 m^2 of retailing space.

Spatial statistical analysis is needed to formally test for the presence of clusters. To use a second-order statistic like the $K(d)$-function, it is necessary to isolate first-order effects, otherwise the stationarity assumption would be violated, and consequently a homogeneous Poisson process would be significantly rejected. Therefore, a case-control design is introduced, which incorporates a heterogeneous environment by using a control point pattern that mimics such background heterogeneity. In this case, the control pattern was determined with a stratified random sample from all 23,983 firms located in the study area, excluding the four supergroups that were previously selected. The selected sample included approximately 10% of the total number of locations in each category of the Herold classification code. This resulted in a control dataset of 2,573 firm locations with a spatial distribution roughly similar to those of the four case point patterns. Using a sample instead of all firm locations was necessary in order to keep the computation of the results to a reasonable time length. The chosen stratified random sampling procedure was used to accurately emulate the firms' diverse locational requirements. The next step focuses on the detection of case clusters relative to the spatial distribution of the controls.

For this purpose, the $\hat{K}(d)$-function was calculated separately for each point pattern of the four cases and the single control pattern. Subsequently, $K_{ii}(d) - K_{jj}(d)$ was calculated. Deviations from H_o would be indicated by either a more clustered pattern ($D > 0$) or a more dispersed spatial distribution of the cases relative to the controls ($D < 0$). Significance was conducted applying 199 point-wise Monte Carlo simulations,[5] leading to a level of significance of $\alpha = .01$. These simulations create a critical envelope. Significant clustering is present when the empirical function lies above the upper part of the envelope; significant dispersion is present when the empirical function lies below the lower part of the envelope. Figure 4 shows the results, with all four $\hat{D}(d)$-functions estimated for distances up to 20 km.

Overall, the four case point patterns show significant differences in the $D(d)$-functions, as the estimations for all $\hat{D}(d)$-functions fall mostly above the upper part of the simulated confidence envelope. These positive values suggest statistically significant spatial clustering for the four postsuburban services locations compared to their controls. Thus, the null hypotheses of randomly distributed patterns of service locations must be rejected and the alternative hypotheses of agglomerated point patterns have to be accepted. This is true for all distances between zero and 20 km. One exception is the creative services point pattern for the first 3 km, where the spatial distribution of creative services locations is not significantly more clustered than the control distribution. But beyond this initial 3 km, the locations show significant clustering through the farthest distance of 20 km. From an economic geography perspective, this means that spatial proximity matters and, following Malmberg and Maskell (2002), that density can boost localized learning

[5]It took approximately 41 hours on a Dell Optiplex 745 computer (Intel Core 2 CPU 6400, 2.13 GHz, 2 GB RAM) to complete 199 Monte Carlo simulations for the four point patterns. We recognize that 199 runs is a low number of simulations and more computing power, if available, would have allowed an increase in the number of simulations to 999 or higher. We therefore advise the reader to interpret the results, especially the significant ones, with some caution.

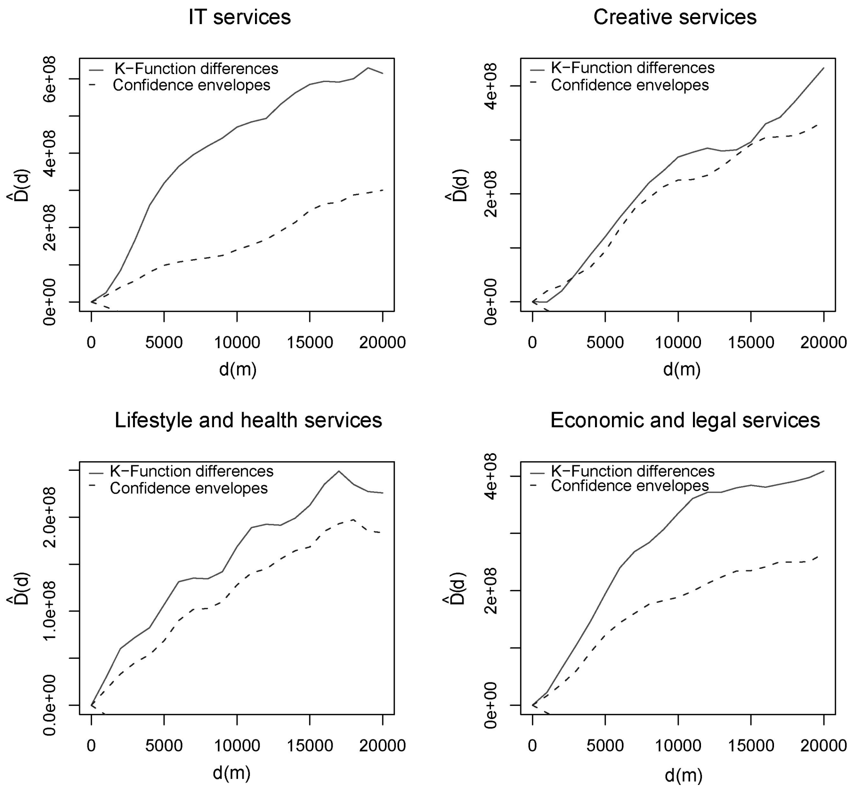

Fig. 4. $\hat{D}(d)$-functions for the four postsuburban service sectors.

and the innovation process. In particular, agglomeration economies foster face-to-face contacts and the creation, exchange, and diffusion of ideas and knowledge, which are essential in such clustering (Storper and Venables, 2004). The comparison between these four services sectors suggests differences in the degree of geographic clustering. The strongest clustering is observable for the IT sector and the weakest for the lifestyle and health services sector.

SUMMARY AND CONCLUSION

Postsuburbanization processes shape urban morphology and, especially, the spatial structure of the urban fringe. This study examined one aspect of that spatial structure, namely the spatial formation of services, and addressed the question of whether Vienna's urban fringe had already developed a polycentric structure. To answer this question, microgeographic data were analyzed within a point process modeling framework. The applied methodology accounted for nonstationarity in first-order effects, meaning that a spatially heterogeneous environment was, *a priori*, included in the analysis using a case-control design. The results of this research show that, in contrast to the Lower Austrian central-place spatial planning program (http://www.ris.bka.gv.at/Dokumente/LrNo/LRNI_

1992062/LRNI_1992062.html) of the 1990s, Vienna's urban fringe had already experienced some functional enrichment.[6]

In terms of its diversity in providing goods and services, the urban fringe is now quite similar to the core city. This can be explained by a change in the supply and demand structure in the outer ring due to the diverse demographic and socioeconomic composition of its inhabitants. These findings are similar to those reported for other European metropolitan areas such as Copenhagen (Hansen and Winther, 2006), Stuttgart (Eisenreich and Schenk, 2002), and the Rhein–Main region (Brake, 2005), where postsuburbanization processes have already been observed. In Copenhagen, Denmark, for instance, the existing service nodes in the outer areas of the metropolis have expanded as newly located knowledge-based firms have emerged. To cite another example, the outer ring of Stuttgart has become economically autonomous and emancipated itself from the core city as a consequence of service enterprises relocating from Stuttgart city into the surrounding fringe. All of these tendencies were confirmed in the Viennese case study.

There is mounting evidence that the urban fringe of Vienna today exhibits a polycentric structure. Results indicate significant functional agglomeration tendencies because postsuburban services are clearly more clustered than other services in the outer ring. This leads to the conclusion that there are specific locational qualities at these clustered locations. However, clusters are also found in traditional suburban areas south of Vienna in the vicinity of the main traffic axis, which ensures heightened accessibility to the core city. These new clusters have developed from existing clusters and have not yet spawned new economic centers. This is not a result of planning regulations or taxes. The reason is that Austria does not have a master plan for designing and reallocating clusters or economic centers. But even though responsibility for planning lies with local communities, there is a certain similarity among communities in the way they handle spatial planning policies.

The results from the kernel estimations reveal only two subcenters flanking the core city. This would define a "bicentric" suburban structure, rather than a true polycentric structure. However, following Clark (2000), the monocentric urban model is no longer applicable to Vienna. Nonetheless, it is important to point out that accessibility and economic competition are still important factors, because the two clusters are located in areas that are most accessible to the largest number of potential customers residing in the metropolitan area. Accessibility and economic competition are essential forces in creating and sustaining new nodes. Findings from this research, however, reject the notion that the core city has lost its importance. Whereas a larger total number of service locations can still be found in the core city compared to the urban fringe, the difference in relative terms (i.e., the number of service locations per 1000 residents) is not that great. In other words, the importance of the core city is (relatively speaking) declining, while the importance of the urban fringe is (relatively speaking) increasing.

In sum, it can be said that the findings agree with Burdack and Herfert (1998) that future European metropolitan areas will be marked by a polycentric urban structure. Proposing a paradigm shift from suburban to postsuburban development is premature. Yet it is clear that "suburbia in its traditional sense now belongs to the past" (Fishman, 1987, p. 205) and that the urban fringe now constitutes an essential part of the metropolis. In the

[6]According to the administrative configuration, Vienna's urban fringe is located entirely within the province of Lower Austria.

near future it can be anticipated that the outer ring will become increasingly self-contained economically and evermore independent from the core city. Thus, the urban fringe will cease to exist as an appendage of the core city.

Following Soja (2001), this is not a contradiction because metropolitan areas cannot yet be fully characterized as postsuburban. Rather, there is a coexistence of suburban and postsuburban processes. Very likely, future research will show whether Vienna's urban fringe has already been shaped by a combination of suburban and postsuburban processes.

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