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Measuring morphological polycentricity - A comparative analysis of urban mass concentrations using remote sensing data

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ABSTRACT

Polycentricity belongs to the most versatile and fuzzy concepts in urban geography. It basically points to the existence of more than one center within a conurbation. Previous studies have mostly referred to the spatial distribution of employment density for (sub-) center identification. In contrast, our study draws on large area 3D building models derived from ubiquitous remote sensing data. We use stereoscopic Cartosat-1 digital surface models in combination with building footprints. These geoinformation reflect the spatial configuration of the built dimension and allow a physical approach to the concept of polycentricity. For (sub-) center identification we thoroughly analyze conceptually different kinds of threshold approaches (global, region-specific and distance-based) applied to concentrations of urban masses. After evaluating the advantages and disadvantages of the threshold approaches applied, we combine these methods to overcome their individual shortcomings. Last but not least, we establish a framework consisting of mapping techniques and site- and non-site specific statistics to evaluate polycentricity at fine-grained spatial intra-urban scale. In general we find that urban mass concentrations are a reasonable proxy for commonly used employment density data. We address the polycentricity issue across four German city regions—Frankfurt, Cologne, Stuttgart and Munich—and we find all of them to still be morphologically dominated by their core cities. Nevertheless, our analysis reveals striking differences of the urban spatial structure highlighting a rather monocentric pattern in the Munich region on the one hand, and a polycentric-dispersed distribution of urban mass concentrations in the Stuttgart region on the other hand.

1. Introduction

Every city has a center, or two, or even more? Today's metropolitan regions of the Global North consist of complex spatial arrangements of centers and subcenters in which economic activity is concentrated. Numerous studies have shown that formerly monocentric metro regions have been transforming into polycentric or even dispersed spatial configurations that are characterized by a diminishing regional primacy of the core cities (e.g. Anas, Arnott, & Small, 1998; Batty, Besussi, Maat, & Harts, 2004; Siedentop, 2015; Zhong et al., 2015). Accordingly, many scholars point out that standard monocentric models of constantly decreasing densities with increasing distances to the center are not reflecting metro regions' today's urban spatial structure (e.g. Adolphson, 2009; Anas et al., 1998; Roca Cladera, Marmolejo Duarte, & Moix, 2009; Siedentop, Kausch, Einig, & Gössel, 2003). This finding is especially true for North American metro regions but similar trends have been observed for Europe as well (Hall & Pain, 2006; Riguelle, Thomas, & Verhetsel, 2007; Garcia-López & Muñiz, 2010; Meijers, Waterhout, & Zonneveld, 2005; Bontje & Burdack, 2005; for an overview see e.g. Krehl, 2016). At the same time, some scholars generally question a trend towards a polycentric pattern of urban functions; instead, they predict a rather flat, edgeless and non-centric urban land use pattern as the spatial outcome of long-term restructuring processes in metro regions (Lee, 2007; Lang & LeFurgy, 2003; Lang, 2000). Despite these seemingly concurring opinions—in terms of restructuring processes towards less concentrated spatial arrangements—, the academic world is far from a consensus in this debate.

If these restructuring processes are limited to issues of urban form and spatial configurations, they are often referred to the term *polycentricity*, which implies that more than one center exists within a conurbation (e.g. Kloosterman & Musterd, 2001; Riguelle et al., 2007; Burger & Meijers, 2011). It should be noted, however, that a clear-cut definition of polycentricity is still missing and that the conceptualization of the same—morphologic, functional or strategic—has not been agreed upon either (cf. Giffinger & Suitner, 2015; Kloosterman & Lambregts, 2001; Münter, Wiechmann, & Danielzyk, 2016).

A major challenge for any empirical investigation of polycentricity is the definition of a *center* and *subcenter*(*s*) (Duranton & Puga, 2015). Generally speaking, a *center* is distinguished from a subcenter or any other kind of spatial densification by its primacy. This primacy is addressed in a number of ways such as its administrative (political)

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dimension, its metropolitan function, or its region-wide importance for economic prosperity to just name a few. Not less challenging is the detection of *subcenters*. Many studies use density indicators in combination with thresholds to distinguish areas with different intensities of economic activity (e.g. Anas et al., 1998; Galster et al., 2001; Giuliano & Small, 1999; Giuliano, Redfearn, Agarwal, Li, & Zhuang, 2007; Kim, Yeo, & Kwon, 2014; McMillen, 2003).

Taking a closer look at the variables considered when addressing hierarchies in urban systems reveals a striking focus: the majority of studies consider economic variables such as firms or employees whereas multi-dimensional analyses are scarce (exceptions are e.g. Barr & Cohen, 2014; Krehl, 2015b; Sarzynski, Hanson, Wolman, & McGuire, 2005). However, urban centers and subcenters are usually not monofunctional spatial entities consisting of only businesses and jobs. They usually contain further functions and can take quite different physical shapes. Previous research has often undervalued the variegated nature of urban and suburban subcenters in terms of physical outcomes and the local context of development.

Moreover, earlier research on the spatial configuration of polycentric urban regions suffers from a spatially narrowed perspective on US-American metro regions (cf. Bogart & Ferry, 1999; Duranton & Puga, 2015). Despite the fact that polycentric regions are an issue in the European debate, few in-depth empirical studies exist (Adolphson, 2009; Guillain & Le Gallo, 2010; Knapp & Volgmann, 2011; Krehl, 2015b; Krehl, 2016; Meijers, 2008). These limitations in terms of the regions covered by empirical investigations and the considered variables still hamper our understanding of polycentricity.

Thus, this paper's contribution is to widen the notion of polycentricity by addressing the built dimension of urban spatial structure. In doing so, we contribute to the academic knowledge by transferring established methods to a new set of variables and therefore offering a more encompassing analytical view. From a methodological perspective, we also elaborate on the prospects that recently generated large area 3D building models derived from remote sensing data provide for comparatively analyzing the morphology of metro regions. Our study will likely not serve as a blueprint, but contribute to a consistent comparative urban research based on thoroughly established thresholds. Geographically, we complement the predominantly North American focus with an empirical study of four German metro regions.

The remainder of this paper is organized as follows. We first review the concept of polycentricity and the most common means of analysis (Section 2). After that, we explain the way we transfer the ideas from the socioeconomic to the built dimension (Section 3). Section 4 introduces the data and the study regions. The precise analytical procedure is provided in Section 5. A presentation and discussion of the results is provided in Section 6 and conclusions are drawn in Section 7.

2. Current state of the polycentricity debate

The scientific debate on the fuzziness of polycentricity is characterized by a sometimes confusing co-existence of theoretical, analytical and normative approaches (see e.g. Brezzi & Veneri, 2015; Giffinger & Suitner, 2015; Münter et al., 2016). A morphological view of polycentricity –which we take in this study– refers to the distribution of objects (see specification below) within a given area, and centers are considered as substantial spatial densifications of these objects (cf. Champion, 2001; Davoudi, 2003). In contrast, a flow perspective asks for spatial linkages between different settlements that are addressed as functional nodes (e.g. with respect to commuting patterns). Functional polycentricity therefore describes an urban region as a network of places that are functionally linked with each other (Green, 2007; Parr, 2004).

Early investigations on polycentricity are essentially based on monocentric models, i.e. a densely populated core city is surrounded by a less dense hinterland; this leads to a concentric distance-based, negative rent gradient originating from the center (cf. Alonso, 1964; Anas & Kim, 1996). However, so-called agglomeration economies—establishing the core city's primacy in terms of density and rents—will eventually turn into diseconomies due to congestion effects. Firms and households will respond by migrating towards less dense locations. What is a priori unclear is whether outmigration will lead to a densified extended core or to the establishment of secondary centers in some distance to the primary center (e.g. Fujita & Ogawa, 1982; McMillen & Smith, 2003). If the latter happens, the formerly monocentric region made first steps towards a more polycentric spatial configuration.

Traditional empirical analyses of urban spatial structure have addressed employees as their primary object of investigation. These analyses' theoretical foundation is rooted in urban economics and most of these strands explain the emergence of one or more centers with the existence of agglomeration economies and spatial spillovers. Since the kind of spillovers introduced in most theoretical contributions occurs due to social interactions (a vast amount of literature discusses the value of face-to-face interaction, e.g. Storper & Venables, 2004; Audretsch & Feldman, 2004), the focus on employees is the logical starting point when analyzing urban spatial structure in general and polycentricity in particular. However, recently derived remote sensing classifications and their combination with spatially fine-grained data regarding employees have permitted (spatial) correlation analyses of the same and thus combined, multivariate analyses of urban spatial structure (cf. Fina, Krehl, Siedentop, Taubenböck, & Wurm, 2014; Krehl, 2015a, 2015b; Krehl, Siedentop, Taubenböck, & Wurm, 2016; Siedentop, Krehl, Taubenböck, & Wurm, 2014).

Next to agglomeration (dis-)economies, public policies are certainly shaping the geographical pattern of employees and residents. Since the 1990s, many metropolitan areas in North America, Asia and Europe have implemented growth management policies that aim at controlling urban growth and directing development to certain places (cf. Anthony, 2004; Landis, 2006; Siedentop, Fina and Krehl, 2016; Siedentop, Krehl, Guth and Holz-Rau, 2016). Against this backdrop, polycentric configurations could be an explicit objective of spatial planning (sometimes referred to as concentrated deconcentration; e.g. Smith, 2011; Sorensen, 2001; Gatzweiler, 1994). Recent contributions further stress the importance of path dependencies of built-up structures (Kloosterman & Lambregts, 2007; Redfearn, 2009; Turok & Mykhnenko, 2007). Finally, Krehl et al. (2016) point out that varying activity and built densities could be the result of urbanization processes and transportation investments at different times.

So, what does this imply regarding polycentricity research? A least common denominator could be that polycentricity is

- a spatial configuration somewhere in between the ‘extremes’ of monocentricity on the one hand and urban sprawl on the other hand,
- not only the result of opposing economic agglomeration forces but also the physical manifestation of spatial planning,
- both, the historical heritage of earlier planning decisions and the manifestation of path dependencies referring to natural/topographic settings.

Complementary to the theoretical explanation of polycentricity, a large body of literature deals with measurement issues. Comparatively simple and well-established techniques to analyze employee distributions are e.g. peak density values (e.g. McDonald & McMillen, 1990) or cut-off methods (‘thresholds’) combining minimum densities and minimum absolute values (e.g. Giuliano & Small, 1991; Siedentop et al., 2003). More sophisticated approaches to identify urban (sub-)centers refer to exploratory (e.g. Arribas-Bel, Ramos, & Sanz-Gracia, 2015; Krehl, 2015b; Riguelle et al., 2007), parametric (e.g. McDonald & Prather, 1994; Roca Cladera et al., 2009) and non-parametric approaches such as locally weighted regression models (e.g. Krehl, 2016; McMillen, 2001; Redfearn, 2007). Despite their common objective to identify spatial densifications, these methods differ with respect to their theoretical reasoning. For that and for the reason of conceptual