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Functional Polycentricity: Examining Metropolitan Spatial Structure through the Connectivity of Urban Sub-centres

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Abstract

A shift from monocentric cities to increasingly polycentric urban regions has been widely recognised in recent research literature. Although polycentricity in general refers to the existence of several adjacent centres within the same area, many studies have emphasised that functional linkages between the centres of an urban system are also an essential part of polycentricity. Despite the increasing number of studies concerning functional polycentricity, research on the subject is still in a development phase. In this paper, a new approach to measure functional polycentricity is presented, in which functional polycentricity is approached through the connectivity of individual centres to the whole urban system. The paper illustrates the potential of the method with empirical case studies addressing the urban spatial structures of three functional urban regions in Finland. In the case studies, detailed commuting data are used in order to measure the degree of functional polycentricity.

1. Introduction

In recent research literature, there is a growing consensus about how the spatial structure of cities in developed societies is becoming increasingly polycentric (Anas *et al.*, 1998; Kloosterman and Musterd, 2001; Parr, 2004; Hall and Pain, 2006). The debate on polycentricity is strongly intertwined with a broader discussion about urban change where cities are no longer seen as mere morphological entities with clear and detectable borders but rather as functional urban regions incorporating large areas around the central city (Parr, 2005; Hall, 2009). To this extent, the spatial logic behind contemporary urban regions follows closely the spatial logic behind Manuel Castells' (1996) concept of a 'space of flows' as the urban form of most urban regions includes a functional network of communities which may be physically

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separate but connected through dense flows of commuting trips and other forms of daily mobility (Hall and Pain, 2006; Hall, 2009).

The theoretical foundations of the concept of polycentricity, however, are far from being solid. Apart from the fact that the concept has gained notable normative connotations, particularly as a buzz word connected with strategic planning within the European Union (EC, 1999; Davoudi, 2003), there is also fundamental fuzziness in its use in a more analytical context (Green, 2007; Meijers, 2008). First, despite the growing consensus on the polycentric development of urban regions, the term 'polycentricity' may refer to the spatial clustering of a number of different phenomena. Principally, as Kloosterman and Musterd (2001) point out, polycentricity can refer to the multinodal development of any human activity. Typically, however, either population or employment distribution is considered.

Secondly, the concept of polycentricity is highly scale-dependent; a system which may be polycentric at one scale may be monocentric when examined at another scale (Hall and Pain, 2006; Taylor *et al.*, 2008). Polycentricity may also be understood differently when measured at different scales (Davoudi, 2003). Traditionally, the concept of polycentricity has been applied at intra-urban scale where the focus has been on the clustering of population or employment within a metropolitan area or functional urban region. Such approaches have strong tradition in the United States (Garreau, 1991; Anas *et al.*, 1998), but recently questions regarding intra-urban polycentricity have also been addressed elsewhere (Bontje and Burdack, 2005; Suárez and Delgado, 2009; Garcia-López and Muñiz, 2010; Yue *et al.*, 2010).

A new scalar approach to the concept of polycentricity emerged a couple of decades ago when the polycentric urban region (PUR) as a research agenda gained ground (Batten, 1995; Kloosterman and Musterd, 2001; Parr, 2004). PUR refers to an interurban scale where a dense network of distinct but adjacent cities exists without a clear leading centre. Most examples of such regions are from Europe (Camagni and Salone, 1993; Hall and Pain, 2006; Meijers, 2007), but there is also similar evidence reported from North America and Japan (Batten, 1995; Lang and Knox, 2009). The most extensive scale related to the concept of polycentricity is the interregional scale (Davoudi, 2003). This approach to polycentricity is linked with European spatial development policies, which aim at achieving balanced spatial development through territorial polycentric development (EC, 1999).

A third source of conceptual confusion relating to the term 'polycentricity' is its usage in both morphological and functional contexts. In strictly morphological terms, the concept of polycentricity refers to several adjacent centres that are located in the same urban system. A number of recent studies, however, have emphasised that functional linkages between the nodes in an urban system are also required in order to call it polycentric (Hall and Pain, 2006; Green, 2007; Burger *et al.*, 2011). Empirical research on functional polycentricity has typically included the measuring of flows between the centres of the polycentric region. However, although an increasing amount of research literature aimed at formally defining and analytically measuring the concept of functional polycentricity has been published, research on the subject is still in a development phase.

In this paper, a new approach for measuring functional polycentricity is introduced. Here, functional polycentricity is approached as the connectivity of individual centres to the whole polycentric urban system rather than as functional relations between the centres. Therefore, instead of addressing directional flows between nodes, functional relations within the polycentric system are measured as interaction surfaces of each centre. These surfaces, or connectivity fields, determine how intensely each centre is functionally connected to the rest of the polycentric system. The aim of the paper is to introduce the connectivity field method and to illustrate its potential with a case study in which the method is tested by analysing the polycentric development of the three largest functional urban regions in Finland. In the case study, the functional polycentricity of both population and employment distribution is measured using detailed commuting data. In order to interpret the degree of functional polycentricity, a measure of morphological polycentricity is also introduced to the analysis. Although the scale in the analysis is intra-urban, the scalability of the method is discussed in the paper.

2. Functional Polycentricity and its Measures

Functional linkages are often assumed to exist between the centres of a polycentric urban system (Kloosterman and Musterd, 2001; Lang and Knox, 2009). A typical example of such functional linkages is commuter flows. As Parr (2004) remarks, an important feature of a polycentric urban region is that the centres of the PUR have overlapping labour markets, which generates complicated internal commuting patterns. However, other forms of spatial interaction can be considered to knit together a polycentric urban system as a single functional entity. Despite the consensus about spatial interaction being an inseparable part of polycentricity, research aiming at formally defining and analytically measuring such interaction has started to emerge only recently.

Evolving functional polycentricity was first observed in research analysing commuting patterns where commuter flows were found no longer to follow the traditional monocentric model but to be increasingly complex (Hamilton, 1982; Cervero and Wu, 1998; van der Laan *et al.*, 1998). Van der Laan (1998) categorised urban regions according to whether the commuting flows in the regions were directed from the suburbs to the central city or vice versa. He defined four types of urban region: centralised, decentralised, cross-commuting and exchange-commuting, of which the three latter hold a functionally polycentric urban pattern. Although the term functional polycentricity occurs rarely in these early studies, which have their background in transport research, evidence of the increasing complexity in commuting patterns clearly indicates evolving functional polycentricity.

A major contribution to conceptualising functional polycentricity *per se* was made by the POLYNET project, which aimed at exploring the association between information flows and polycentric development at the regional scale (Hall and Pain, 2006). Building on world-city literature (Sassen, 1991; Scott, 2001; Taylor, 2004) and on Castells' (1996) concept of a space of flows, the project's case studies addressed functional polycentricity by analysing business network connections and information flows, which are generated by advanced producer services (Taylor *et al.*, 2006; Hoyler *et al.*, 2008). The analysis utilised an interlocking network model which measures the intercity network of intrafirm information flows on the basis of office locations (Taylor, 2001). Their findings highlighted the complexity and scale dependency of the concept of polycentricity as the level of polycentricity tends to decrease when the spatial scale increases (Taylor *et al.*, 2008).

Drawing on the POLYNET research, Green (2007) developed a formal method of defining functional polycentricity. He emphasises that a functionally polycentric network is not tied down to physical location: functional relations within the morphologically polycentric system may change without changes in the physical location of the nodes. Building on social network analysis, Green (2007) measures functional polycentricity in terms of network density, which is a ratio of the actual flows under study to the total potential flows. Although network density provides a useful tool to analyse the functional organisation of a spatial system, it has been criticised as being incapable of measuring functional polycentricity properly in certain situations as hierarchically organised urban systems may have high network density and centres with equal connectivity may have relatively low network density (Burger and Meijers, 2012).

Another approach used for measuring the degree of functional polycentricity in an urban system is the gravity model (de Goei *et al*., 2010; van Oort *et al*., 2010). In the gravity model, the interaction between the spatial units is explained by their size and the distance from another, similar to Newton's law of universal gravitation. In a fully functional polycentric system, the interaction between the nodes should be solely determined by the gravity model and no signs of hierarchy should be evident. De Goei *et al*. (2010) used Poisson regression in order to explore whether the commuting patterns in south-east England meet these conditions. Their findings indicated functionally polycentric development at the intra-urban scale, but to a lesser extent at the interurban scale. Applying the same approach, van Oort *et al*. (2010) found similar evidence in their analysis of the functional integration of the Randstad region using data on interfirm relationships.

Burger *et al*. (2011) analysed the commuting flows in English and Welsh city-regions in order to examine the degree of polycentricity in both functional and morphological terms. They used a variety of indices to measure the degree of polycentricity including network density, primacy index (the ratio of commuting flows or employment between the central city and the rest of the city-region) and outward openness (the ratio of commuters from other city-regions compared with total employment). Furthermore, building on the commuting patterns introduced by van der Laan (1998), Burger *et al*. (2011) assessed the level of functional polycentricity of the city-regions according to the degree of cross-commuting and the degree of exchange commuting. They conclude that although the city-regions have become more polycentric in both functional and morphological terms, their spatial structure differs considerably and some regions have even become more monocentric (Burger *et al*., 2011).

Linked to this research on English and Welsh city-regions, Burger and Meijers (2012) developed the analysis further based on the logic behind the primacy indices in order to combine the morphological and functional aspects of polycentricity in a way that both could be measured in a coherent manner. Building on Preston's (1971) approach to central place theory, Burger and Meijers used the rank–size distribution of nodality scores (i.e. the absolute importance of the centre) to assess the degree of morphological polycentricity and, likewise, the rank–size distribution of the centrality scores (i.e. the importance of the centre related to its surrounding) to measure the degree of functional polycentricity. Their indicator for polycentricity is a log-linear regression line of the rank–size distribution where a flat slope indicates a polycentric urban region. Their findings were similar to those of Burger *et al.* (2011), indicating major variation in the level of polycentricity between the urban regions.

3. Data and the Case Study Areas

Data used in this study are obtained from the Monitoring System of the Spatial Structure maintained by the Finnish Environment Institute. The system offers register-based data for the whole of Finland in five-year intervals starting from 1980 (Helminen and Ristimäki, 2007). The data are aggregated to 250×250 metre grid cells, which enable very detailed analysis independent of administrative boundaries. The commuting data include the origin (the place of residence) and destination (the location of workplace) grid cell for each commuter. Thereby, the data are not based on the actual commuter flows. Data from the years 1980 and 2007 were used and all the grid cells within the study area, apart from those completely covered by water, were included in the study.

The case study areas cover the functional urban regions (FURs) of the three largest urban areas in Finland: Helsinki, Turku and Tampere. The functional urban regions are defined according to Parr's (2007) definition where a FUR constitutes of a central, densely built city and its surrounding area, which is dependent on the workplaces of the central city. In this study, the central built-up area is defined using the spatial cluster analysis of aggregated population and employment counts.[1] The study area includes all the municipalities from which at least 25 per cent of the employed workforce commutes to the central city area (Figure 1). This procedure resulted in coherent functional urban regions, which in 2007 had total populations of 1.26 million in the Helsinki region, 325 000 in the Turku region and 379 000 in the Tampere region.

4. Methodology

4.1 Sub-centre Identification

A wide range of methods to identify intra-urban sub-centres have been used. Early approaches to detect sub-centres utilised simple cut-off values which were adjusted according to local knowledge (McMillen, 2001). Giuliano and Small (1991), for instance, in their study on the Los Angeles region defined an employment sub-centre as having at least 10 000 workplaces at a minimum density of 10 employees per acre. More formal approaches have utilised parametric methods where the outlying residuals of a monocentric regression model of employment density are used to mark sub-centres (McDonald and Prather, 1994) or non-parametric methods, which make use of geographically weighted regression in order to allow for local variation in the density surfaces (McMillen, 2001). More recent approaches have detected urban sub-centres through spatial cluster analysis (Baumont *et al.*, 2004; Riguelle *et al.*, 2007) or kernel density analysis (Leslie, 2010).

Since the data used in this study constitute high-resolution grid cells, a sub-centre is understood as a local cluster of cells. Therefore, spatial cluster analysis is used for sub-centre identification. Several methods exist for defining the location of spatial clusters and a local version of Moran's *I* described by Anselin (1995) is used here. The method detects local agglomerations of high values and calculates the statistical significance level for each spatial cluster. Due to spatial autocorrelation in the data, the levels of statistical significance are influenced by the problem of multiple comparisons creating a risk that the typical 0.05 significance level may be too liberal. The statistical significance level also has a direct effect on the number of identified sub-centres. A conservative significance level decreases the

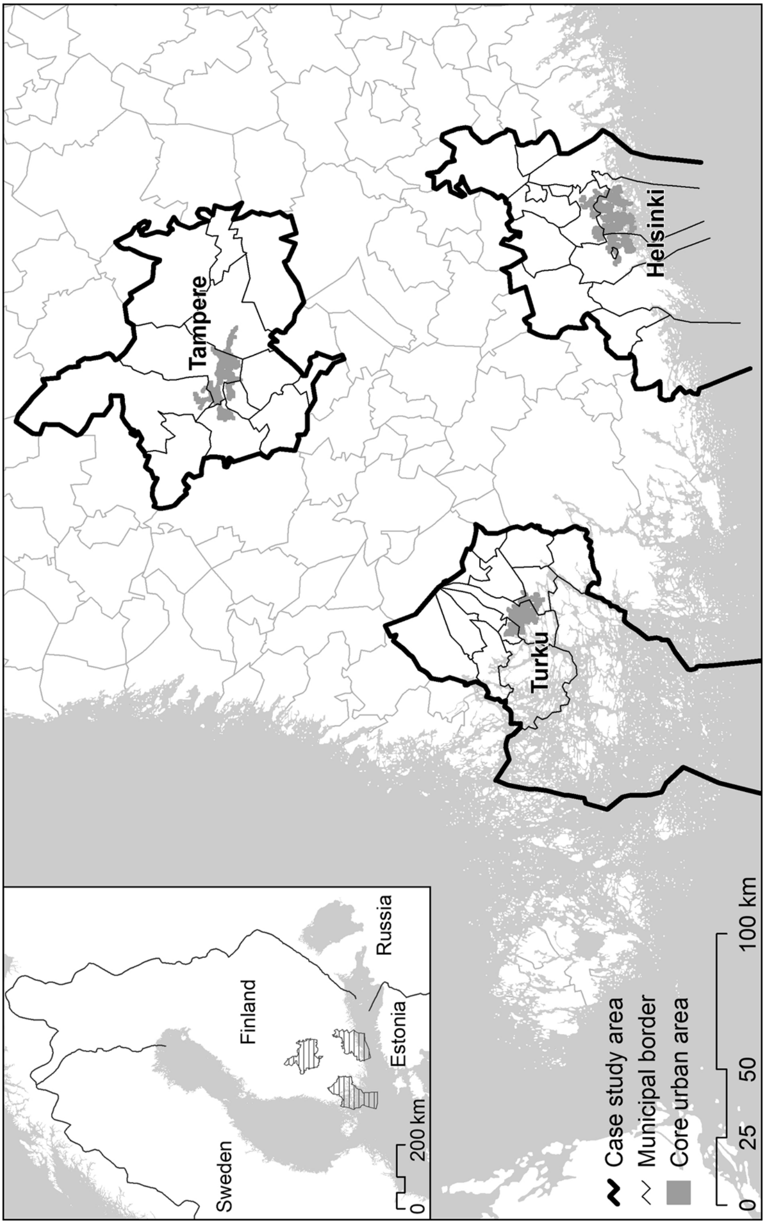

Figure 1. Case study areas.
Map source: National Land Survey of Finland.

number of spatial clusters but a too liberal significance level may have a similar effect if distinct spatial clusters agglomerate together. Therefore, the choice of the used statistical significance level is not only a means to control correct bounds of statistical reasoning, but it can also be used to adjust the sub-centre identification process according to local knowledge. In this study, a significance level of 0.01 was considered to generate a sub-centre structure that most adequately resembles the urban form of the study areas.

Since spatial cluster analysis determines local non-randomness in the data, it will also detect rather weak spatial clusters. To eliminate small and practically insignificant spatial clusters, a cut-off value is applied. In order to make the cut-off value sensitive to local variation in each of the study areas, the cut-off value is defined in relative terms where sub-centres having a population or employment representing less than 0.5 per cent of the regional total are excluded from the study. Of the remaining spatial clusters, the largest was considered as the urban core area and the rest as sub-centres. In the case where several earlier separate sub-centres have merged together during the study period, all previously separate sub-centres are considered as one centre in order to enable unbiased longitudinal comparison.

Figure 2 illustrates the population and employment centres in all three study areas in 1980 and 2007. The figure shows that the development of population and employment distribution have taken a rather different form. In terms of population distribution, major developments have been taking place in the core areas where a number of sub-centres, which were still separate in 1980, have sprawled together by 2007. Apart from the Turku region, the development of new population sub-centres has been modest. The development of employment distribution has taken rather a different form. In all three case study areas, the number of sub-centres has increased notably, particularly around the ring roads, whereas the geographical sizes of the core area have not changed much. In Turku and Tampere, many industrial sub-centres that still existed in 1980 have disappeared. In strictly morphological terms, it seems that the intra-urban spatial structure of these three urban regions has become increasingly polycentric in the terms of employment distribution, while population distribution does not show clear development towards a polycentric spatial structure.

4.2 Connectivity Fields as a Measure of Functional Polycentricity

Functional polycentricity has typically been examined using measures that derive from the internodal flows of people or information within the polycentric system. In this paper, however, functional polycentricity is approached as the connectivity of individual centres to the whole polycentric urban system. Instead of addressing directional flows between nodes, functional relations within the polycentric system are approached through the surfaces of interaction where the surface, or connectivity field, determines how intensely a particular centre is functionally connected to the rest of the polycentric system.

The advantage of the connectivity field approach over the internodal approach is that it considers the totality of functional flows within the urban region, not only flows between the centres. In this regard, the connectivity field method resembles the bottom–up approach of identifying functional urban regions developed by Coombes *et al.* (1986). In the bottom–up approach, FURs are identified using an algorithm that optimises the regional boundaries on the basis of a full set of commuting data (Robson *et al.*, 2006; Davoudi, 2008). In contrast, the top–down approach uses predetermined core areas as a

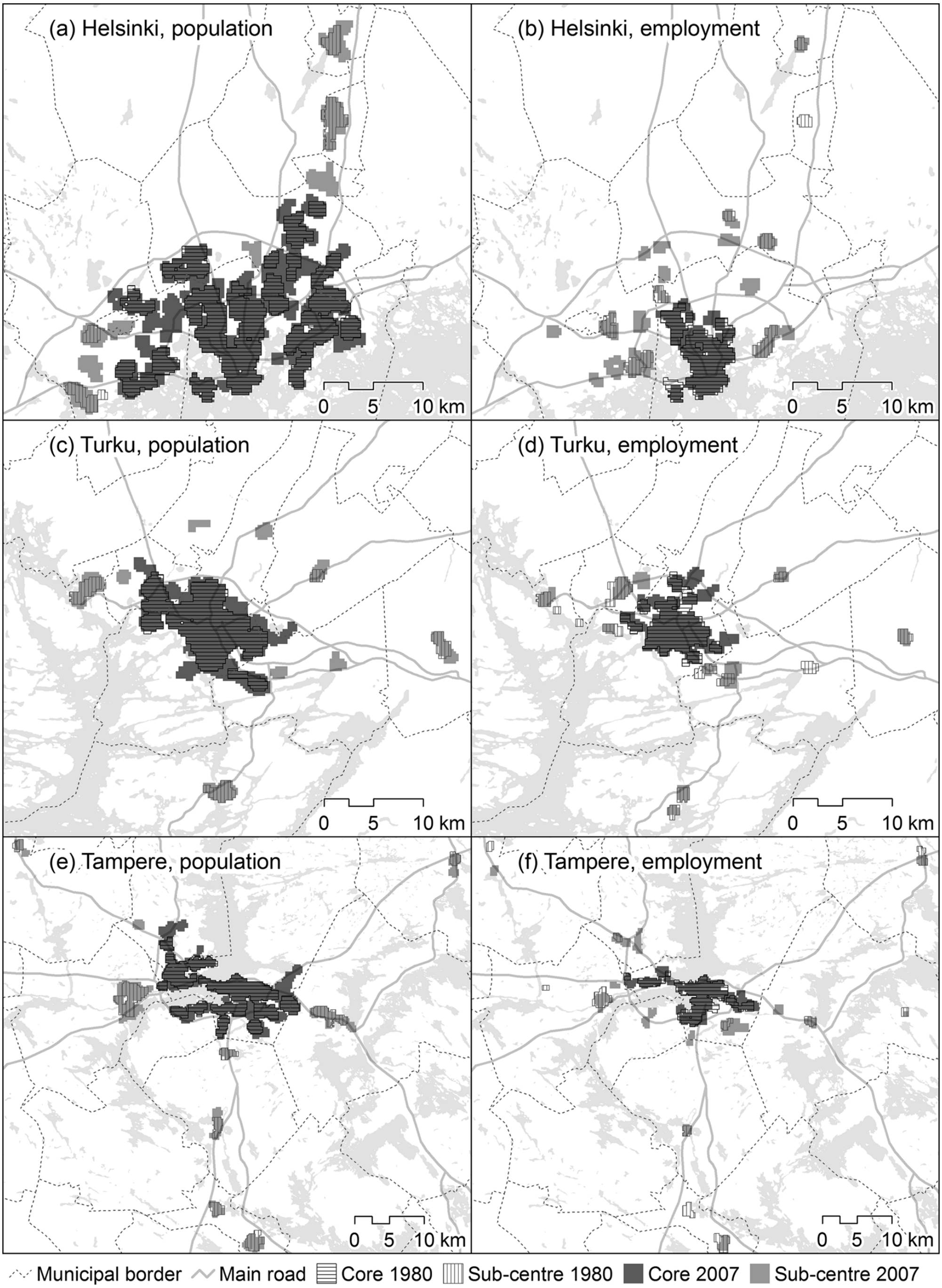

Figure 2. Urban core and sub-centres in 1980 and 2007. (Note the different scale in panels (e) and (f)).
Base map source: National Land Survey of Finland.

starting-point in identifying FURs and certain commuting thresholds are applied to determine the FUR boundaries. As a whole, the bottom–up approach provides a more comprehensive way of analysing urban systems compared with the top–down approach, which focuses on flows between pre-defined nodes (Davoudi, 2008).

The connectivity fields are calculated using a flow attribute which may be any interaction data that have origin and destination locations, such as commuting, shopping trips, telephone and e-mail traffic, business networks or international flights. The connectivity field of a particular centre is comprised of the distribution of destination locations that have their origin in the centre. Internal flows, which have both origin and destination in the same centre, are omitted from the analysis. As a result, the connectivity field reveals the degree to which each centre is functionally connected to the other parts of the urban system. The level of connectivity is determined by comparing each connectivity field with a potential field, which is formed from the distribution of the total number of destinations in the interaction data. The more the connectivity field of a particular centre resembles the potential field, the more connected the centre is with the rest of the region.

This can be illustrated through a simple example where commuting in a hypothetical urban region having a core area and three employment sub-centres is considered (Figure 3). In Figure 3(a), the connectivity field of sub-centre 1 (SC1) is illustrated. The darker the tone in the diagram, the more workers living in that particular location commute to the SC1. Similarly, the connectivity field of the sub-centre 2 (SC2) is illustrated in Figure 3(b). Figure 3(c) shows the potential field for commuting, which is determined by the distribution of places of residence for all employees in the region. It is clearly visible from Figure 3 that SC1 is more connected to the urban region as it attracts commuters not only from nearby locations, but also evenly throughout the region. SC2, on the other hand, has a much more local labour market and thus also lower connectivity to the region.

In order to formally measure the level of connectivity, the R^2 statistic of ordinary least squares (OLS) is used to estimate whether the relationship between the connectivity field and the potential field distributions is linear. If a linear relationship exists, the connectivity field of the centre in question has a more or less equal distribution with the potential field suggesting that the centre is functionally connected to the rest of the urban system. The connectivity field that differs from the potential field

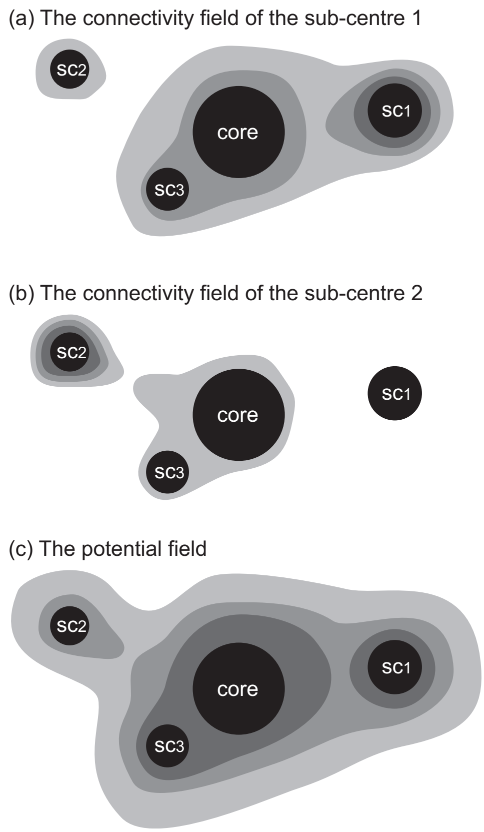

Figure 3. An example of the connectivity field method.

implies limited functional connectivity. The higher the R^2 value, the more closely the connectivity field resembles the potential field and, thereby, the more functionally connected the centre is with the rest of the urban system. In the example illustrated in Figure 3, the R^2 value for SC1 would presumably be high, well above 0.5, whereas the same value for SC2 would be considerably lower.

The overall degree of functional polycentricity of a given region is measured from the average connectivity values of the centres. The higher the average connectivity level of all centres in the urban system, the more functional linkages exist within the system, hence suggesting a high degree of functional polycentricity. However, in addition to examining the overall degree of functional polycentricity, the connectivity field method also enables one to examine the connectivity of a single centre to the urban system and, therefore, to evaluate the spatial extent of functional polycentricity. In other words, the connectivity field method can be used to evaluate whether the whole polycentric urban system is functionally interlinked or if this applies to only some of the centres thus revealing internal functional dynamics in the urban system.

5. Empirical Analysis of Polycentricity in Finnish Urban Regions

5.1 Morphological Polycentricity

In strictly morphological terms, polycentricity refers to the existence of several adjacent centres in a given region. In polycentricity literature, however, polycentric urban systems are usually assumed to have an even distribution of inhabitants or workplaces between the centres (Parr, 2004; Meijers, 2008; Burger and Meijers, 2012). Following this line of reasoning, morphological polycentricity is examined here by comparing the population and job counts of the centres within the case study areas.

Table 1 shows that all case study areas seem to be morphologically more or less monocentric. Whether population or

Table 1. Changes in population and employment distribution, 1980–2007

	Population			*Employment*		
	1980	*2007*	*Percentage change 1980–2007*	*1980*	*2007*	*Percentage change 1980–2007*
Helsinki						
Core area	590 776	780 178	32.1	219 052	276 830	26.4
Sub-centres	58 132	142 882	145.8	40 255	153 711	281.8
Core/sub-centre ratio	0.10	0.18	86.1	0.18	0.56	202.1
Turku						
Core area	170 507	191 572	12.4	51 817	81 764	57.8
Sub-centres	17 751	35 551	100.3	13 806	18 671	35.2
Core/sub-centre ratio	0.10	0.19	78.3	0.27	0.23	–14.3
Tampere						
Core area	173 162	231 298	33.6	62 866	93 293	48.4
Sub-centres	42 691	61 745	44.6	18 188	36 136	98.7
Core/sub-centre ratio	0.25	0.27	8.3	0.29	0.39	33.9

employment is considered, all the sub-centres' figures together do not amount to the figures of the respective core areas. In 2007, the population sub-centres amounted to only from 18 to 27 per cent of the inhabitants of the core area depending on the region. The most even distribution was visible in the Tampere region where the study area includes a few relatively large and densely populated towns that are not incorporated into the core area (see Figure 2). In terms of employment, the ratios between the sub-centres and the core areas were somewhat higher ranging from 23 per cent in the Turku region to 56 per cent in the Helsinki region.

When the change in morphological polycentricity from 1980 to 2007 is considered, a clear trend of increasing polycentricity becomes visible. In all cases, urban core areas have grown moderately, by about 10 to 50 per cent. The sub-centres, however, have grown in many cases at a much faster pace, the growth rates ranging from 45 to 145 per cent for population and from 35 to 280 per cent for employment. The highest sub-centre growth rates are visible in the Helsinki region where the number of employees in the employment sub-centres has increased remarkably from 40 000 to over 150 000. It seems that, in the terms of employment distribution, Helsinki is rapidly developing towards polycentric region as, in addition to an increase in number of the employees, the number of sub-centres has increased considerably, particularly along the ring roads (see Figure 2).

The growth rates of sub-centres in the Turku and Tampere regions are more diverse. Whereas the number of inhabitants has doubled in the population sub-centres in Turku, the population growth rate of the sub-centres in the Tampere region was basically at the same level as in the core area indicating rather modest polycentric development. An opposite finding is visible for employment distribution. The employment sub-centres in Tampere have almost doubled in size, whereas the growth of employment sub-centres in Turku has been more moderate than in the core area suggesting development towards a more monocentric spatial structure. This finding, however, can be explained by a drastic decrease of industrial jobs in some sub-centres of the Turku region from 1980 to 2007 and, regardless of the declining core/sub-centre ratio, new employment districts have developed along the ring road similarly to the Helsinki region.

5.2 Functional Polycentricity

Table 2 shows the average R^2 values indicating the level of functional polycentricity. In 2007 the overall degree of functional polycentricity in the three case study areas ranged from 0.2 to 0.4 for employment centres and from 0.5 to 0.6 for population centres indicating differences in their general functional structure. The considerably lower degree of functional polycentricity of employment centres implies that they have more local labour market compared with population centres. In other words, people living in the population centres seem to commute diversely across the urban region, whereas the employment centres seem to attract a larger number of local commuters, thus making their functional structure more monocentric.

Despite the relatively high overall degree of functional polycentricity, the connectivity levels of the urban core areas are still notably higher than those of the sub-centres. However, the connectivity values of the sub-centres, ranging from 0.18 to 0.56, suggest that also they have significant functional connectivity within their respective regions. In general, the sub-centres seem to be more functionally than morphologically polycentric as in most cases the ratios

Table 2. Changes in the degree of functional polycentricity, 1980–2007

	Population			*Employment*		
	1980	*2007*	*Percentage change 1980–2007*	*1980*	*2007*	*Percentage change 1980–2007*
Helsinki						
Overall	0.532	0.606	13.9	0.317	0.400	26.2
Core area	0.824	0.904	9.7	0.921	0.884	–4.0
Sub-centres	0.460	0.563	22.4	0.242	0.367	51.7
Core/sub-centre ratio	0.56	0.62	11.6	0.26	0.42	58.0
Turku						
Overall	0.255	0.526	106.3	0.176	0.236	34.1
Core area	0.805	0.876	8.8	0.860	0.875	1.7
Sub-centres	0.118	0.487	312.7	0.124	0.178	43.5
Core/sub-centre ratio	0.15	0.56	279.3	0.14	0.20	41.1
Tampere						
Overall	0.204	0.411	101.5	0.112	0.227	102.7
Core area	0.442	0.774	75.1	0.843	0.873	3.6
Sub-centres	0.175	0.371	112.0	0.045	0.178	297.3
Core/sub-centre ratio	0.40	0.48	21.1	0.05	0.20	283.7

between core and sub-centres are considerably higher in Table 2 than in Table 1. However, it must be noted that the ratios are not fully comparable between the tables as the values presenting morphological polycentricity in Table 1 are sums of all the inhabitants or workplaces in the sub-centres, whereas Table 2 shows the average connectivity values for the sub-centres. Therefore, an identical core/sub-centre ratio in Tables 1 and 2 would suggest greater polycentricity in functional than in morphological terms.

Table 2 shows that the overall functional polycentricity levels have increased considerably in all regions from 1980 to 2007. This trend becomes even clearer when the core areas and the sub-centres are considered separately. On the one hand, the functional connectivity of core areas has in most cases increased only slightly or even decreased. The connectivity of the sub-centres, on the other hand, has grown markedly with the fastest growth rates taking place in Turku and Tampere. In these regions, both population and employment sub-centres, characterised by rather low connectivity in 1980, appear to have amalgamated functionally with their urban regions during the studied period. Therefore, the development in Turku and Tampere seems to be following a polycentric development similar to that apparent in the Helsinki region where sub-centres already had rather high connectivity levels in 1980.

5.3 Functional and Morphological Polycentricity Compared

The findings presented thus far suggest that the case study regions are more polycentric in functional than in morphological terms. In this section, the comparison between the two measures of polycentricity is deepened by a joint analysis of functional and morphological polycentricity. In the analysis, the individual polycentricity level for each centre is examined in relation to their distance to the city centre. The level of functional connectivity is measured using R^2 values as described earlier. Morphological polycentricity, however, is approached in relative rather than absolute terms in order to enable comparison. The degree of morphological polycentricity is measured as the proportion of inhabitants or workplaces in each centre, thus yielding a figure ranging between 0 and 1. Although this figure is not fully comparable with the R^2 value,[2] it enables the comparison of both measures on the same scale.

Figure 4 shows that in morphological terms all of the case study regions are indeed very monocentric. A clear majority of all inhabitants and workplaces are located in the core areas leaving only fractions to the sub-centres, which forms L-shaped trend lines in Figure 4. Although an explanation for this lies in the large geographical area covered by the cores thus resulting in large population and employment counts, it does not explain the increase in functional polycentricity apparent, particularly through the rapid increase of the connectivity of the sub-centres. Figure 4 shows that the connectivity levels have increased notably in all regions. Particularly rapid growth has taken place in the population distribution of Turku and Tampere where the trend line has changed from a rather steep curve to almost linear indicating a significant increase in the degree of functional polycentricity. Although this trend is not as striking in the employment centres as in the population centres, the tendency towards functionally more polycentric urban structures is nevertheless clearly visible.

Since the levels of functional and morphological polycentricity are shown separately for each centre in Figure 4, it is possible to examine the internal dynamics of polycentric development within the regions. The changes in the degree of morphological polycentricity are small, as is apparent from the practically identical trend lines of morphological polycentricity in 1980 and 2007. Therefore, although a trend of increasing polycentricity is visible in absolute terms in Table 1, this observed development disappears when the centres are examined separately in relative terms. Conversely, the internal structure of the functionally polycentric development has changed significantly. The most notable increases in connectivity have taken place in the sub-centres located approximately 10–20 kilometres from the city centres, whereas changes in the centres located further away from the central areas have been more modest. It therefore seems that, at least in terms of commuting, intensive functional polycentric urban development has been limited to rather small areas within the urban regions.

6. Conclusions

A substantial amount of research literature has addressed polycentricity both empirically and conceptually. Yet, despite numerous demands to clarify the concept (Davoudi, 2003; Parr, 2004; Hoyler *et al.*, 2008; Meijers, 2008), the term 'polycentricity' has been surrounded by a certain fuzziness as regards to its formal definition and analytical measurement. This paper has contributed to the discussion on measuring urban polycentricity, an issue which Burger and Meijers (2012) bring forth as the next step in the polycentricity debate. In the paper, a new method of measuring functional polycentricity has been introduced where the degree of polycentricity is measured through the connectivity of the urban centres to the rest of the polycentric urban system.

The empirical results support the findings of Burger and Meijers (2012) who concluded that the urban regions in the Netherlands seem to be more polycentric in functional rather than in morphological terms. This

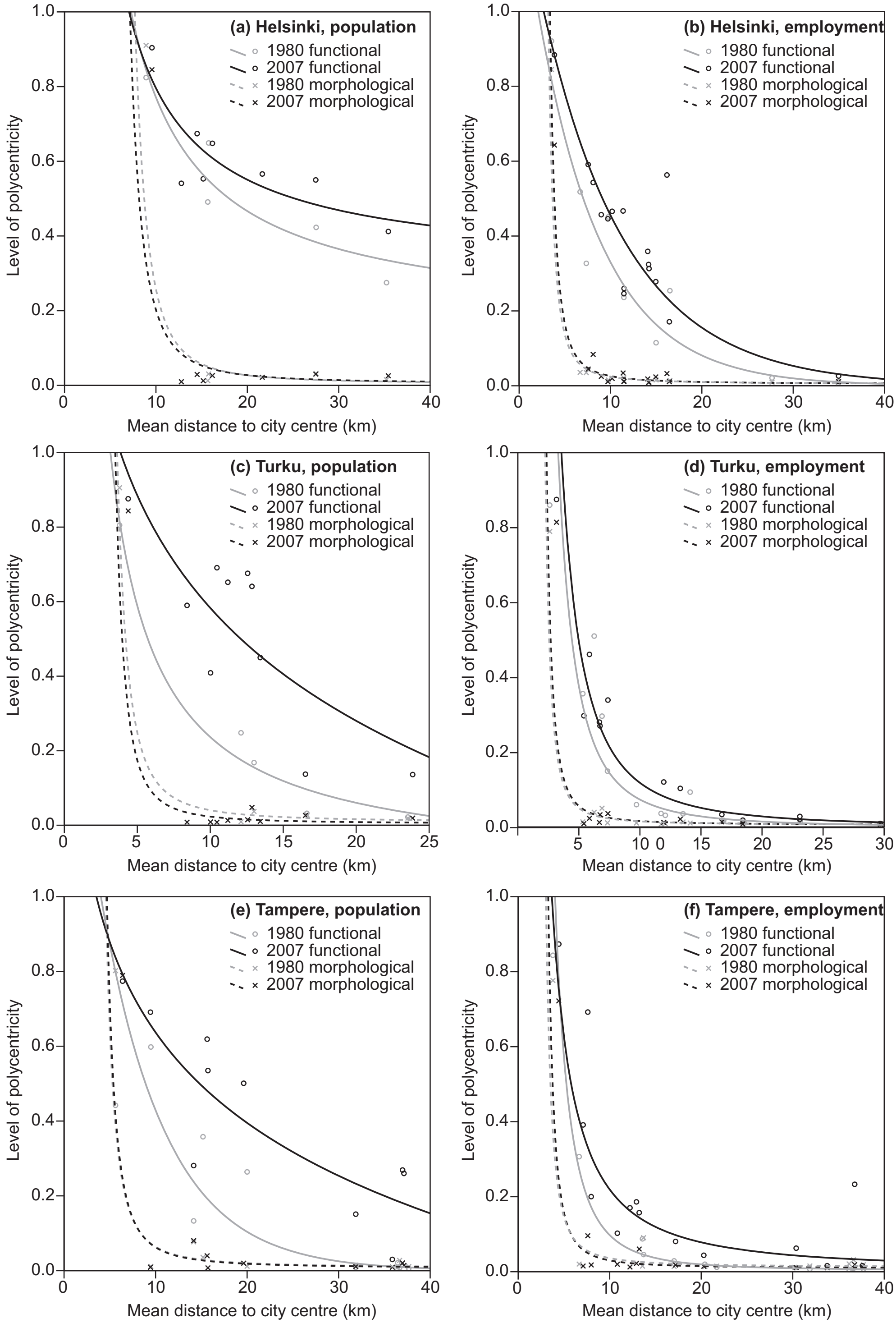

Figure 4. The relationship between functional and morphological polycentricity.

finding is in line with the observation that cities have changed from mere morphological objects to increasingly functional entities better determined by flows than physical structure (Hall, 2009). It seems that urban regions are indeed increasingly characterised by Manuel Castells' (1996) 'space of flows'. However, despite the evidence of increasing functional polycentricity in Finnish urban regions, the paper has shown that the intra-urban spatial structure, in morphological terms, is still more or less monocentric. Similar evidence has been reported in several other studies (for example, Halbert, 2004; Musterd *et al*., 2006; Suárez and Delgado, 2009; Garcia-López and Muñiz, 2010; Yue *et al*., 2010). It is clear that, despite certain development towards polycentricity, the importance of central cities is far from being threatened.

The particular strength of the connectivity field method lies in its ability to examine the internal dynamics of functional polycentricity. The empirical analysis showed how the increased functional polycentricity has primarily been an outcome of the increased connectivity of the inner sub-centres, located typically along the ring roads. This 'ring road effect' emphasises the importance of transport infrastructure in functional polycentric development (see Giuliano *et al*., 2012). It is not surprising that centres which are easily reachable from every corner of the urban region also tend to be functionally connected with the rest of the region. Furthermore, the empirical findings highlight the relatively small size of the functionally polycentric urban regions in Finland. Following Castells's (1996) spatial logic, it seems that in Finnish urban regions, the area characterised by the space of flows seems to cover only rather limited areas of polycentric urban systems.

The scalar focus in this paper has been intra-urban. The connectivity field method, however, is fully scalable and it can be utilised also at interurban or even higher scales, as long as applicable interaction data are available. On a global scale, for example, international air traffic could be used as interaction data where the connectivity field of each region would be the number of daily or weekly flight connections to other regions in the world and the potential field would be the total number of all flights arriving at each region. The analysis would thereby yield high connectivity for regions with dense intercontinental and regional flight connections whereas those regions having connections only with a few other regions would have a low level of connectivity.

The major limitation of the connectivity field method is the poor availability of applicable data. The method requires complete datasets covering the whole population under study, which limits the use of survey data, for instance. In intra-urban or interurban research settings, commuting data are widely used as they are often the only available high-quality interaction data (Parr, 2005; Burger *et al*., 2011). However, at higher scales where commuting does not provide realistic information about the daily flows of people, similar interaction data are rarely readily available. The availability of applicable data is also linked with another shortcoming of the method. As available data are often economic in nature, the method effectively omits the socio-ecological spaces that shape the functional structure of the urban regions as well (Davoudi, 2008). Other interaction data, such as social visits, trips to cultural or leisure amenities and commodity or waste flows, for instance, might form completely different connectivity patterns within urban regions. Such data, however, are rarely available, at least at the required level of detail.

This paper has introduced a new method of analysing functional polycentricity together with empirical examples from the three largest urban regions in Finland. Since the empirical results are presented primarily for demonstrative purposes, the results are very general in nature and further research is needed in order to understand what explains a high connectivity in one centre whereas another, seemingly similar, centre may have a much lower degree of connectivity. Subjects for further research could, for example, include an analysis of the relationship between connectivity and knowledge-intensive economies (Taylor *et al.*, 2006) or connectivity and demographic trends (Champion, 2001). The feasibility of applying the connectivity field method in different contexts should also be further tested using different data at different scales.

Notes

1. The procedure of identifying urban cores is similar to the sub-centre identification presented in section 4.1.
2. In functional terms, a fully polycentric situation would yield R^2 values close to 1 for all centres under study. In a fully morphologically polycentric situation, the measure for all centres would be close to $1/n$, where n is the number of centres. However, in both cases, a fully polycentric situation would yield a horizontal regression line, whereas a fully monocentric situation would effectively yield an L-shaped logarithmic regression line.

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