

Urban Spatial Structure and Labor Productivity in U.S. Metropolitan Areas

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Abstract

Over the years, the consensus has emerged in economic geography and spatial economics that agglomeration enhances productivity and employment growth. At the present day and age, many empirical studies have convincingly shown that there exists a positive relationship between a city's size and its performance, not only in economic, but also in social and environmental terms. Despite considerable empirical evidence on the presence and extent of agglomeration externalities, little attention has been paid to aspects of urban spatial structure. In particular, contemporary empirical work on agglomeration tends to ignore the post-industrial polycentric spatial organization of agglomeration and the geographically extended spatial scales of agglomeration economies. In this, it is assumed that nowadays agglomeration externalities are not only confined to a well-defined single urban core, but, instead are shared among a group of functionally linked settlements.

The objective of his paper is to analyze the size of agglomeration externalities in differing metropolitan spatial organizations, ranging from monocentric to polycentric and from centralized to dispersed. Here, we are particularly interested in the question whether a network of nearby cities may provide a substitute for a single larger city. We address these issues by estimating OLS and 2SLS models explaining labor productivity across U.S. metropolitan regions, thereby including urban spatial structure (size, dispersion, polycentricity) next to the commonly found factors as the capital-labor ratio and educational attainment. We find a positive and significant effect of polycentricity on labor productivity, particularly for smaller metropolitan areas. One explanation is that the spatial range of agglomeration advantages has been regionalized, while agglomeration diseconomies remain relatively more limited to the local level.

Keywords: Polycentricity, Dispersion, Spatial Structure, Labor productivity, Regional externalities, Borrowed size

JEL-classification: J24, R14, R12

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1. Introduction

Nearly all handbooks on urban economics and economic geography start with explaining the very existence of cities. The key idea is that spatial proximity to other people and businesses is advantageous as it allows for potentially beneficial interactions between economic actors. The larger the city, the larger the potential productivity gains or *urbanization externalities* in terms of labor market pooling, good infrastructure, public facilities, amenities and knowledge spillovers (Isard, 1956). Lately, many empirical assessments have stressed the positive relationship between city size and their performance, not only in economic, but also in social and environmental terms (Glaeser et al., 1992; Ciccone and Hall, 1996; Quigley, 1998; Ciccone, 2002). These benefits of locating in cities manifest themselves in the striking pace and scale of urbanization around the globe. 2008 provided a landmark year as, for the first time in history, more than half of the world population lived in cities (UNFPA, 2007).

Somewhat paradoxical at first sight is the trend that many of the benefits of the city can nowadays be accessed from places well beyond the city boundaries (Coe and Townsend, 1998; Parr, 2002; Phelps, 2004). This becomes visible in long-standing processes of residential suburbanisation, which have been followed by the deconcentration of manufacturing industries, commerce and retail activities, producer services, and urban entertainment centres, though at different speeds and with varying location preferences, ending in both old and new centres (Garreau, 1991), a process that appears to be stronger in the United States than in Europe. Or, as some have argued, not end in centres at all, but in a dispersed pattern (Gordon and Richardson, 1996; Lang, 2003; Glaeser and Kahn, 2004). At the same time, a selection of specialized urban functions concentrated, in particular headquarter and knowledge-intensive activities for which face-to-face contacts remain important (Hall, 1999; Glaeser and Kahn, 2001). Processes of deconcentration appear stronger in the U.S. than in Europe (Riguelle et al., 2007). Although in a globalizing world the costs of moving goods have sharply decreased, it is still very expensive to move people. This, in turn, induces the concentration of certain economic activities (Glaeser and Kohlhase, 2004).

These simultaneous processes of concentration and particularly deconcentration have made the industrial image of a city as being composed of an urban core and a rural hinterland increasingly obsolete. The emerging spatial form of post-industrial cities is quintessentially polycentric (Hall, 2000; Kloosterman and Musterd, 2001; Phelps and Ozawa, 2003), and what is 'urban' increasingly spreads out over a wider region, requiring us to think of the city as a regional phenomenon (Scott, 1988; Storper, 1997; Calthorpe and Fulton, 2001). The apparently increasingly widening geographical scale at which agglomeration economies operate manifests itself in the revival of the debate on city-regions (Parr, 2005) and in the conceptualisation of regionalised urban entities, such as 'global city regions' (Scott, 2001), 'megalopolitan areas' (Lang and Dhavale, 2005), 'polycentric mega city-regions' (Hall and Pain, 2006) or simply 'megaregions' (Regional Plan Association, 2006; Florida et al., 2008). In spatial terms, such regions' spatial structure can be characterised as 'a series of anything between 10 and 50 cities and towns, physically separate but functionally networked, clustered around one or more larger cities' (Hall

and Pain, 2006: 3), or 'integrated sets of cities and their surrounding suburban hinterlands' (Florida et al., 2008: 459). In other words, it seems that we are witnessing not only a process of decentralization of urban activities from the city center or CBD to new centres in the city or at its edges – the development of a 'polycentric city' - , but also the fusion (Champion, 2001) of several such polycentric cities in wider polycentric regions (Batten, 1995; Kloosterman and Musterd, 2001). Essential to this debate on such regionalized urban entities is the underlying idea that external economies are not confined to a well-defined single urban core, but, instead, are shared among a group of functionally linked settlements (Phelps and Ozawa, 2003; Sassen, 2007). In this, it is inherently assumed that in the present day and age economic agglomerations are no longer isolated spatial entities, but interact at least to some extent (Fingleton, 2003; Burger et al., 2009).

The basic idea of polycentricity is that multiple centres or cities, and hence multiple sources of agglomeration economies, are co-located and also interact given the widening geographical scale of economic and social processes. This 'regionalisation' of urbanization externalities has been described by several scholars, thereby deploying terms such as 'urban network externalities' (Capello, 2000), 'spatial externality fields' (Phelps et al., 2001), 'regional externalities' (Parr, 2002) or 'network economies' (Boix and Trullén, 2007). Such concepts build on the concept of 'borrowed size', coined by Alonso (1973), who used it to explain why smaller cities that are part of a megalopolitan urban complex had much higher incomes than self-standing cities of similar size. According to Phelps and Ozawa (2003), 'the idea of borrowed size suggests that today's examples of megapolitan agglomeration are based predominantly on some combination of pecuniary and technological externalities open to service industries across a group of settlements, rather than the technological externalities available at the localized scale of discrete towns or cities (pp. 594).'

Identifying mega-city regions as well as concepts to label regionalized agglomeration externalities reflects an underlying desire for analysis to correspond to actual changes in the geographical scale at which agglomeration manifests itself and agglomeration externalities appear to operate (Richardson, 1995; Moulaert and Djellal, 1995; Coe and Townsend, 1998; Parr, 2002). However, 'the diffuse, sprawling and endlessly mobile metropolis is fundamentally different from the city as we have known it' (Sudjic, 1992: 297), which makes that our equipment to make sense of what is happening, has lagged far behind the changes (Amin and Thrift, 2002). It is particularly striking to see that contemporary analyses of agglomeration externalities tend to ignore the post-industrial polycentric spatial organisation of agglomeration and the geographically extended spatial scales of agglomeration externalities (Cheshire, 2006; Lee and Gordon, 2007). In part, this is because regions are typically delimited from a (single) nodal perspective (see Parr, 2008). It appears that classical analysis of agglomeration is unable to reveal the full operating of such regionalised agglomeration economies. When external economies are increasingly conceptualised in relation terms (Gordon and McCann, 2000; Phelps and Ozawa, 2003; Johansson and Quigley, 2004), it would make sense to study agglomeration externalities at the scale of the regional urban system rather than the single city as the interactions with nearby cities may influence also agglomeration externalities.

Despite an extensive literature on changing urban systems, the influence of the regional urban system, and how it is shaped, on its performance remains an understudied theme. In equilibrium approaches, the economic organisation of space is not a concern (see Corpataux and Crevoisier, 2007). Scott (2000) and Kloosterman and Musterd (2001) notice that, most often, the shape of the urban system is simply taken for granted. On average, urban economic analyses do often not go any further

than including urban density or city size as spatially relevant factor, but density nor size do reveal everything about the efficiency of a region's spatial organisation. The main contribution of this paper is to overcome some of the afore-mentioned quandaries by analysing the direct and indirect effects of the shape of the regional urban system on the economic performance of U.S. metropolitan areas in terms of labor productivity. In this, a region's spatial structure is measured primarily along the dimension monocentric-polycentric, while also the centralization-dispersion dimension is addressed. In addition, this article examines whether spatial structure moderates the effect of urbanization economies on labor productivity at the regional metropolitan scale. In other words, it is analysed whether a network of (smaller) cities in the wider metropolitan region may provide a substitute for the urbanization externalities of a single larger city.

The remainder of this article is organized as follows. We synthesise the literature discussing the spatial organization of regions in relation to urbanization externalities in Section 2. Section 3 presents our measurements of the spatial structure of metropolitan regions. Section 4 continues with the model specification and other data used. Section 5 presents the estimation results. Section 6 concludes and discusses the implications of our findings.

2. Urbanization externalities, spatial structure and labor productivity

2.1. Urbanization Externalities

Research on the effect of city size can be traced back to Marshall's theory of agglomeration developed at the end of the 19th century. The core of Marshall's argument was that a local concentration of economic activity takes in a number of cost-saving benefits or productivity gains for firms. According to Marshall, these benefits derived from co-location would be uncontrollable and unregulable for a single company and, above all, were thought to be immobile or spatially constrained. Although Marshall only focused on single-industry areas and sector-specific externalities (internal to the industry), later the framework of agglomeration externalities would be expanded with external economies accessible to all companies in a geographical concentration irrespective of the sector concerned (see e.g., Hoover, 1948; Isard, 1956; Jacobs, 1969). In the economic and geographic literature, these benefits stemming from the size or density of the urban economy would become better known as urbanization externalities.

As a general rule, urbanization externalities can be regarded as external economies passed to firms as a result from savings from large-scale operation of the agglomeration or city as a whole, independent of industry structure (Henderson 1986; Van Oort, 2004). Following Isard (1956), it is the availability of a large and multi-functional labor pool and the presence of a good infrastructure and public facilities in dense economic areas that are sources of urbanization externalities. Relatively more densely inhabited localities are also more likely to accommodate universities, R&D laboratories, trade associations, and other knowledge generating institutions. It is the dense presence of these organizations that supports the production and absorption of know-how, stimulating innovative behavior, and contributes to disparities in regional economic growth (Harrison et al., 1996). Moreover, the often diverse industry mix in an economic dense area increases the odds of interaction, generation, replication, modification and recombination of ideas and applications across different sectors. Finally, the presence of a large internal market offers a larger degree of stability and low transport costs (Siegel et al., 1995), while the diverse industrial structure protects a region from volatile demand

(Frenken et al., 2007). On the other hand, too densely populated areas may also result in a dispersion of economic activities due to pollution, crime or high land prices. In this respect, one can speak of congestion effects, which are assumed to be negatively related to productivity.

Nevertheless, according to many regional scientists, urbanization externalities can be regarded as the origin of uneven economic growth across regions as in some areas firms can profit to a larger extent from these external economies than in other regions. In their seminal work *The Making of Urban Europe*, the economic historians Hohenberg and Lees (1985) document a strong correlation between geographic agglomeration of economic activities and economic growth in Europe during the Industrial Revolution. Likewise, recent empirical investigations on contemporary economic development have shown that the elasticity of average labor productivity with respect to employment density, as proxy for urbanization externalities, generally ranges between four and thirteen per cent, while accounting for between twenty and fifty per cent of the regional differences in average labor productivity in the Western world (Bode, 2004).

2.2. Spatial structure and urban performance

Spatial structure tends to get increasing interest from urban planners as it is believed to affect the economic performance, environmental sustainability and social well-being of places and their inhabitants. A clear example of this rising attention are the 'new urbanism' and 'smart growth' movements in urban planning circles in the U.S. However, in economics, spatial structure and its influence on a region's performance remains an understudied theme. Most often, empirical work on agglomeration does not go beyond including average density or city size as spatially relevant factor, but density nor size do reveal much of a region's spatial organisation. Certainly when economic performance, in terms of labour productivity, is measured, it makes sense to use indicators of urban spatial structure that refer to spatial concentration since, as was just outlined, productivity tends to grow when there is increased concentration of urban activity.

These indicators need to address two questions. First, to what extent is the metropolitan population located in urban centres or dispersed? Second, how is the urban population spread over urban centres? The first question refers to a centralization-dispersion dimension, the second to a monocentric-polycentric dimension.

Dispersion

A dispersed spatial structure, also referred to as urban sprawl, refers to the situation in which a large part of the population is not living in centers but spread out across the territory in a non-concentrated pattern. There seems rather common agreement that dispersion negatively influences urban performance, which is not surprising as it diminishes the possibilities to reap the benefits of urban concentration. Already in 1974, the Real Estate Research Corporation concluded in the well known study 'The Costs of Sprawl' that sprawl is the most expensive form of residential development in terms of economic costs, environmental costs, natural resource consumption, and many types of personal costs (Real Estate Research Corporation, 1974, pp. 2-7, cited in Cervero, 2001). According to a 2000 Costs of Sprawl report (Transportation Research Board, 2002), this conclusion still holds until today. Compared to more compact forms of development, sprawl consumes more land and infrastructure, provides fewer fiscal impacts, while it increases housing costs, personal travel costs and automobile dependence (p.21). Yet, sprawl fulfills a widespread need for safe

neighbourhoods, appreciating housing values, and unrestricted use of automobiles (p.20) and Glaeser and Kahn (2004) stress exactly the association of sprawl with significant improvements in quality of life. According to 2000 Costs of Sprawl study, the alternative is a form of centralization that directs development to locations where it is more efficient to provide public services. This is known as 'smart growth'. In this study we will test the hypothesis that metropolitan regions that have a higher proportion of the population living in urban places, and hence, less dispersion, perform better in terms of labor productivity.

Polycentricity

Contrary to dispersion, the influence of monocentricity or its opposite, polycentricity, on the performance of larger metropolitan regions remains unclear due to a lack of empirical research. We therefore address this issue in more detail. Despite the empirical deficit at the metropolitan scale, however, informative for our question of how polycentricity affects urban performance are also findings relating to polycentricity at the scale of individual cities and at the national scale as similar principles might apply to the regional scale of wider metropolitan regions that stands central here.

Bertaud (2004) finds that the monocentric city model enhances transport efficiency, as it reduces trip length (see also Clark and Kuijpers-Linde, 1994; Cervero and Wu, 1998; Schwanen et al., 2004), thereby increasing the share of sustainable travel modes, and as a consequence of both, reducing the total amount of pollutant emitted by transport. At the same time, concentration of pollution is higher in monocentric cities. The multiplicity of origins and destinations of trips in polycentric cities is a hindrance to transit operation as well. Urban spatial structure would also affect the welfare of the poor. While the transport efficiency of monocentric cities enhances their job access, it also implies higher land prices and more expensive housing than in more polycentric cities. Finally, polycentricity is assumed to hamper economic efficiency as it leads to a fragmentation of the metropolitan labor market, while the latter is often identified as the most important explanation for the higher productivity of larger cities (Bertaud, 2004). Fragmentation as a result of polycentricity was for instance found for New York (Godfrey, 1995) and Paris (Halbert, 2004). However, recently, Lee and Gordon (2007) did not find a relationship between urban form and economic growth for a selection of U.S. metropolitan regions. It was found that a polycentric spatial structure of a city, as opposed to monocentrism, and measured by the subcenters' share of all center employment, does not affect metropolitan population and employment growth. Similar results are found for dispersion, which is measured as the share of metropolitan employment dispersed outside city centers. Regarding dispersion, however, an interaction effect with population size was revealed. Smaller cities were found to grow faster when they have a more clustered spatial form, whereas a more dispersed spatial structure led to higher growth rates in larger cities (Lee and Gordon, 2007).

At the national level, polycentricity refers to the presence of several larger metropolitan areas contributing to a country's economic performance, whereas a situation of dominance in terms of size and economic significance of one larger metropolitan region over several comparatively small metropolitan regions is referred to as monocentrism or urban concentration. In Europe, 'polycentric development' policies are in fashion as many nations try to achieve a more balanced development of their urban system (Waterhout et al., 2005). Despite their popularity, however, the theoretical and empirical underpinning of polycentric development strategies remains weak. Economic growth models are not very specific, if mentioned at all,

about the development of urban systems and about the role the urban system plays in balancing growth. Moreover, empirical analysis shows that countries that have already a polycentric urban system are neither characterized by less regional disparities (Meijers and Sandberg, 2008) nor is there a relationship with GDP per capita development (IGEAT et al., 2008). Of particular interest is also Henderson's (2000) study of the effects of urban concentration on economic growth for countries. It was found that the form of urban concentration, measured as the share of the largest city in the national urban population, has profound effects on economic growth. More developed and larger countries tend to have a lower optimal degree of urban concentration. Henderson found that a large number of countries are too concentrated in 1990 (for instance, Canada, Denmark, Finland, Hungary, New Zealand and the United States), while a couple of countries have too little concentration (among which Belgium, Malaysia, the Netherlands).

However, a potential drawback of Henderson's study is the way in which spatial structure is measured. Also Henderson argues that it would be more desirable to incorporate each city's share in the national urban population into the measurement of urban concentration. However, the unavailability of time-series data makes him and others (Ades and Glaeser, 1995) fall back on urban primacy, thus providing only information about the size of the largest city compared to the total urban population. Henderson suggests that given the strong evidence on Zipf's Law (Gabaix, 1999) we may assume that knowledge of the largest city gives us in general a strong clue of what the remainder of the urban system looks like. However, urban primacy does not make clear whether the population outside of the main urban core is concentrated in a limited number of other larger cities, spread over many smaller cities, or dispersed over the country's territory. In the first situation of polycentricity, we would expect to find more benefits of agglomeration and concentration than in the case of dispersal. Take for instance the Netherlands, one of the few countries that shows too little urban concentration according to Henderson (2000). In this small country, the second (Rotterdam) and third largest city (The Hague) tend to be not that much smaller than the largest urban area (Amsterdam). Moreover, they are located very close to the largest city, which has given rise to discussions about considering the larger metropolitan region of which the three cities are part, the so-called Randstad area, as one functional entity and to the need for strategic planning at the scale of this metropolitan region (Lambooy, 1998; Meijers et al., 2003; OECD, 2007; Van Oort et al., 2009). The same applies to Belgium, where the major cities Brussels, Antwerp and Ghent are within easy commuting distance (Cabus and Vanhaverbeke, 2006).

It is exactly for such types of regions – the so-called polycentric urban regions (Kloosterman and Musterd, 2001) – that the debate about the relationships between spatial structure and performance at the scale of the wider metropolitan scale is getting off the ground. As can be learned from discussions on polycentricity at the scale of cities and countries, the crucial question is whether a polycentric urban system at the metropolitan scale allows for enjoying economies of scale, scope and complexity similar to their monocentric counterparts, without, however, incurring the same costs or agglomeration diseconomies that the latter entail. If we were to believe the regional development strategies for regions as the Randstad and the Flemish Diamond, as well as for the many other examples in Europe (see e.g. Meijers et al., 2008), planners and administrators have such high expectations indeed. Some validity may be hidden in these expectations when many of the benefits of urban concentration can indeed be accessed from locations well outside the agglomeration and regional externalities develop. The idea that agglomeration economies are increasingly associated with a more dispersed regional spatial structure has taken

root in the literature (Parr, 2002; Capello and Camagni, 2000; Sassen, 2007). This may particularly hold when these close-by cities are strongly related, as Johansson and Quigley (2004) suggest that, in theory, networks may substitute for spatial proximity: 'for many transactions, an established network reduces the effective distance between nodes, reducing the transaction (or transport) costs that would otherwise be prohibitive. When co-location is infeasible, networks may substitute for agglomeration' (2004: p.175). Technological advance should be considered the main driving force behind this substitution, although it remains unclear to what extent this substitution may take place (Johansson and Quigley, 2004) and whether it also holds for networks between cities rather than between firms.

The reason that polycentricity may be an advantage indeed, is that this 'regionalisation' of agglomeration advantages appears to come coupled with a continued 'localisation' of agglomeration disadvantages. There is some evidence that agglomeration diseconomies remain largely confined to the agglomeration (Parr, 2002). It appears that smaller cities have a greater endogenous capacity to keep these social, economic and environmental costs under control (Capello and Camagni, 2000). However, despite the popularity of the concept of polycentric development – at least, in Europe – it remains unproven that a polycentric spatial structure in metropolitan regions leads to successful economic development (Parr, 2008; Parr, 2004; Lambooy, 1998). Therefore, a hypothesis tested in this paper is that a polycentric urban structure has a direct and positive effect on urban performance.

2.3. Urbanization externalities and polycentricity: interaction effects

Whereas there appears to be some theoretical consensus on the fact that urban externalities are regionalizing, the extent to which such a 'regionalisation' may take place in a polycentric spatial structure is highly questioned. According to Bailey and Turok, 2001, the idea that the integration of separate cities results in agglomeration advantages comparable to similar-sized monocentric cities is 'rather simplistic'. Parr (2004; 2008) points in this respect at the need for longer travel flows, longer commodity flows and less convenient flows of information in polycentric urban regions. Moreover, it should be reckoned that 'some of the advantages of urban size stem from the nature of the metropolitan environment, and are related to such factors as density, proximity, face-to-face contact, informal structures, unplanned interaction, etc.' (Parr, 2004, p. 236), and consequently hold less for polycentric urban regions. This is confirmed by a recent study (Meijers, 2008a) that showed that polycentric regions in the Netherlands had significantly less cultural, leisure and sports amenities than monocentric regions in which the urban population concentrated in a single city.

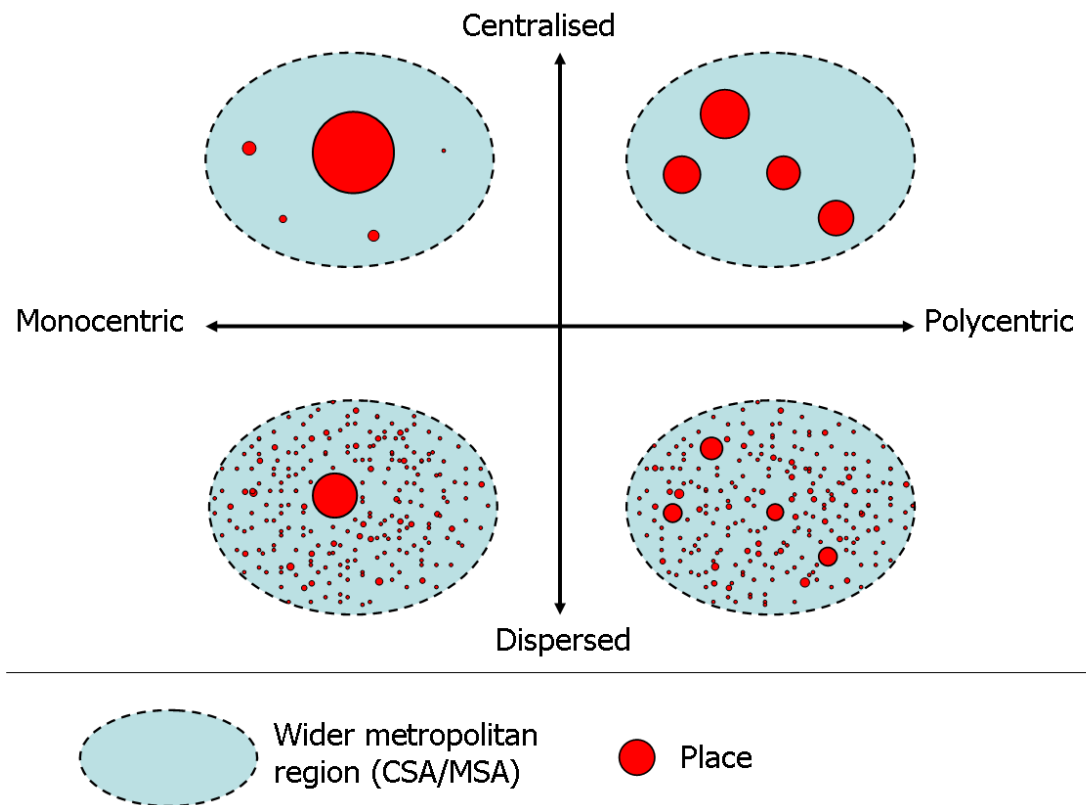
Given the relative absence of empirical research on spatial structure in relation to urbanization externalities, further research is urgently needed to solve this debate (Lambooy, 1998; Kloosterman and Musterd, 2001; Parr, 2004; Turok and Bailey, 2004; Cheshire, 2006; Parr, 2008; Meijers, 2008a). In this paper we test the hypothesis that polycentricity moderates the effect of urbanization economies on labor productivity at the regional metropolitan scale.

3. Quantifying metropolitan spatial structure

A prerequisite for testing the idea of urbanization economies being dependent on spatial structure is to quantify this regional spatial structure. The degree of spatial concentration is of most interest. Here we distinguish two relevant dimensions, quite similar to the two types of spatial concentration discerned by Anas, Arnott and Small

(1998) in their classic essay on cities' urban spatial structure (see also Lee and Gordon, 2007). They discern a centralization and a concentration dimension. At the larger regional scale, we believe that two dimensions are important when studying regional externalities: monocentricity versus polycentricity and centralization versus dispersal (see Figure 1). The polycentricity dimension reflects the extent to which urban population and employment is concentrated in one city or spread over multiple cities in the wider metropolitan region. The dispersal dimension refers to the extent to which population and employment is centralized in cities or dispersed over smaller non-urban places in the region in a non-centralized pattern. Their exact measurement is discussed below.

Figure 1. Dimensions of regional urban form.



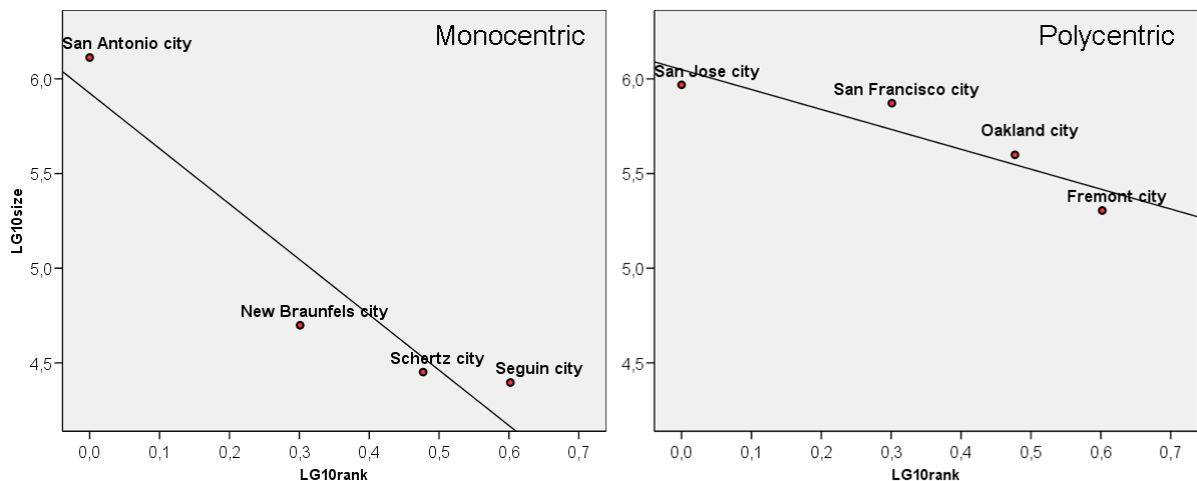
Monocentricity versus polycentricity

In the literature, one finds different interpretations of what makes a region polycentric (Meijers, 2008b). Grossly speaking, there is an approach that defines polycentricity on the basis of urban morphology, while another approach adds relational aspects to it in the sense that a region can only be considered polycentric when the cities are strongly functionally linked, which is sometimes referred to as 'relational polycentricity' or 'functional polycentricity' (see for instance Hall and Pain, 2006; Green, 2007; De Goei et al., 2009). Champion (2001), who also identifies the previous approaches, adds a third, even more restrictive approach, which is that each city has a specialist function in the region (thus suggesting complementarity). Here, we adhere to the first and least restrictive vision, thus studying polycentricity from a morphological perspective (see Kloosterman and Musterd, 2001; Parr, 2004).

A polycentric system lacks strong hierarchy (Kloosterman and Lambregts, 2001), in the sense that there is no city dominating strongly over other cities in each and every respect. The rank-size distribution of the regional urban system provides

information on this hierarchy and is therefore an excellent indication of the extent of mono- or polycentricity (Spiekermann and Wegener in Nordregio *et al.*, 2004). Parr (2004) also proposes the rather flat size distribution of cities in a region as one of the defining characteristics. Figure 2 presents the four largest incorporated places in two U.S. metropolitan regions and also the regression line that best fits the distribution of their sizes. The flatter this line is, the more polycentric the region. Conversely, the more steep, the more monocentric. In this example, San Antonio, TX, is obviously monocentric, while San Jose-San Francisco-Oakland, CA, is a clear example of a polycentric region.

Figure 2. Rank-size distributions to measure mono/polycentricity.



In this study we calculated the slope of the regression line of the rank-size distribution of incorporated places (cities)ⁱ in each U.S. metropolitan region. We did so for different numbers of incorporated places per metropolitan region (2, 3 and 4) and then calculated the average of these three scores.ⁱⁱ

The rank-size distribution does not provide information on the spread of cities over the metropolitan territory. This is, however, also of relevance. According to Parr (2004), a distinctive feature of a polycentric urban region also is a minimum spatial separation between the cities (see also Kloosterman and Lambregts, 2001). Therefore, we need to filter out regions that are polycentric in terms of the rank-size distribution, but that are part of the same contiguous built-up area. In the latter case, the term polycentric conurbation is more appropriate. If the two largest cities of a polycentric metropolitan region belong to the same 'urban area', which are delineated by the US Census Bureau to encompass densely settled territory, we labelled these 'polycentric conurbations'. We did not include these polycentric conurbations in the analysis as it could be argued that these regions, while scoring polycentric, in fact resemble monocentric cities more, the main difference being the presence of administrative boundaries dividing the urban territory (see Appendix A).

Centralization versus dispersion

The second dimension of a metropolitan regions' spatial structure expresses the degree to which population and economic activity in a metropolitan region are centralized in urban places or spread out over smaller non-urban places. The share of the central city in total metropolitan area population in the U.S. fell rapidly from almost 64% in 1930 to 38% in 2000 (Kim, 2007). The question then is where the majority of the metropolitan population is located; are they clustered in other urban centres or are they dispersed over the metropolitan territory in an uncentered way,

thus resembling urban sprawl? In order to test the hypothesis that less centralization and thus more dispersion limits labour productivity, we scored each case study region on a centralization – dispersion axis, their position being dependent on the share of the metropolitan population that was not located in urban centres of at least 25,000 inhabitants in 2006. Note that this interpretation of sprawl deviates somewhat from its definition at a lower spatial scale (see Transportation Research Board, 2002; Lee and Gordon, 2007), as it does not depart from densities. However, it is exactly this interpretation that is central in the common interpretation of smart growth, namely, to provide for ‘concentrated deconcentration’, even of rather low-density urban development.

Association of dimensions

Both dimensions are associated in the sense that more polycentric regions tend to be characterised slightly more often by dispersion. But, as Table 1 displays, there are exceptions to this rule. For instance Midland-Odessa, TX, is the most polycentric metropolitan region, while it is also among the top 5 most centralized regions.

Table 1. Most monocentric, polycentric, centralized and dispersed metropolitan regions in the U.S.

<i>Rank</i>	<i>Most monocentric</i>	<i>Most polycentric</i>	<i>Most centralized</i>	<i>Most dispersed</i>
1	Lincoln, NE	Midland-Odessa, TX	El Paso, TX	Greenville-Spartanburg-Anderson, SC
2	Tallahassee, FL	Santa Barbara-Santa Maria, CA	Lincoln, NE	Portland-Lewiston-South Portland, ME
3	Jacksonville, FL	Johnson City - Kingsport - Bristol (Tri-cities), TN-VA	Phoenix-Mesa-Scottsdale, AZ	Columbia – Newberry, SC
4	El Paso, TX	Salt Lake City-Ogden-Clearfield, UT	San Diego-Carlsbad-San Marcos, CA	Pittsburgh-New Castle, PA
5	San Antonio, TX	Greenville-Spartanburg-Anderson, SC	Midland-Odessa, TX	Youngstown-Warren-East Liverpool, OH-PA

4. Model, data and estimation strategy

4.1 Model

In regional science and urban economics, there are a considerable number of empirical studies that have investigated the effect of urbanization externalities using aggregate production functions at the city level. Although different functional forms of the urban production are existent, our point of departure is the models developed in Ciccone and Hall (1996) and Ciccone (2002), who use a Cobb-Douglas production function to assess the effect of agglomeration economies on localized labour productivity.

Consider the following production function of a metropolitan economy with production factors capital (K), labor (L), human capital (H), materials or intermediate inputs (M) and land (N) in which a single good is produced that is a composite of all the outputs of all producers in that metropolitan area (1),

$$Q = AK^{\kappa}L^{\lambda}H^{\varepsilon}M^{\mu}N^{\nu},$$

in which Q is the nominal output and E captures labour efficiency. In equation (1), A represents an efficiency parameter or vector of exogenous influences on the nominal output measuring Total Factor Productivity. Amongst others, the efficiency parameter A here reflects the urbanization externalities and metropolitan spatial structure (the degree of polycentricity and dispersion). Given constant returns to scale ($\kappa+\lambda+\varepsilon+\mu+\nu=1$), equation (1) can be rewritten as (2)

$$\left(\frac{Q}{L}\right) = A \left(\frac{K}{L}\right)^\kappa \left(\frac{H}{L}\right)^\xi \left(\frac{M}{L}\right)^\mu \left(\frac{N}{L}\right)^\nu, \quad (2)$$

in which the output per worker (labor productivity) is a function of the capital-labor ratio, human capital-labor ratio (or alternatively, education per worker), intermediate inputs-labor ratio, land-labor ratio, and the efficiency parameter A . By taking logarithms on both sides of equation (2), the multiplicative form can be converted into a linear stochastic form, to give the following testable equation (3):

$$\ln\left(\frac{Q}{L}\right) = \theta_0 + \kappa \ln\left(\frac{K}{L}\right) + \xi \ln\left(\frac{H}{L}\right) + \mu \ln\left(\frac{M}{L}\right) + \sigma \ln\left(\frac{N}{L}\right) + \sum_j \theta_{j+1} (\ln X_j) + r_j + \varepsilon \quad (3)$$

, where the equation is now also augmented with a set of variables X with parameters θ , which are related to metropolitan size and spatial structure and enter the production function through a higher value of A (Fogarty and Garofolo, 1988; Broersma and Oosterhaven, 2009). In our case, this set includes the size of the metropolitan population, the degree of polycentricity, and the degree of dispersion. Following Ciccone (2002) we include regional dummy variables r_j to account for differences in exogenous Total Factor Productivity, such as relative differences in price levels and levels of technology across regions.

4.2 Data and Variables

To estimate our production function, data was gathered for the widest possible definition of metropolitan regions, the Combined Statistical Areas (CSAs), as well as for all those metropolitan statistical areas (MSAs) that are not part of a CSA. Data concerns those metropolitan regions located in continental U.S that had a total population of at least 250,000 inhabitants in 2006. The reason to primarily focus on CSAs - the widest definition of metropolitan regions in the U.S. - comes forward from the necessity to analyse the performance of cities in their wider spatial context. Moreover, we wanted to avoid a single nodal definition of metropolitan regions as the assumption that is at the heart of this paper is that it is necessary to include the regional urban system a city is part of as urbanization externalities may have regionalised. For example, it was deemed necessary for this analysis to take the San Jose- San Francisco – Oakland CSA as unit of analysis rather than the MSAs that make up this CSA separately (e.g. San Francisco, San Jose, Napa, Santa Cruz, Santa Rosa, Vallejo). The selection of metropolitan regions included in our analysis is presented in Appendix A.

Our dependent variable *Labor Productivity*, is measured as the 2006 GDP in real dollars of a metropolitan area (excluding agriculture, fishing, hunting, mining and public administration) divided by the total number of jobs (excluding self-employment) in the included sectors in that area in 2006. Data on GDP by metropolitan area and sector were obtained from the U.S. Department of Commerce's Bureau of Economic Analysis (BEA). Data on the number of jobs were provided by the Bureau of Labor Statistics (BLS) of the U.S. Department of Labor, and for individual sectors taken from the 2006 American Community Survey. The new BEA estimates enable a more direct measurement of labor productivity than previously possible, when many researchers used indirect proxies such as the mean annual wage or household income. Descriptive statistics are provided in Table 2. Note that corresponding specification (3), all non-dummy variables in our empirical analysis are log-transformed.

With respect to the factor inputs, the *Capital-Labor Ratio* within a metropolitan area was measured by linking the capital-labor ratio of (broad) sectors, as obtained from the Annual Survey of Manufacturers, to the industrial composition within the metropolitan area (based on a division into 15 sectors, excluding agriculture and public administration). Hence, the obtained value is a weighted average of the capital-labor ratio across sectors. Although this operationalization does not account for regional differences within sectors (e.g., level of technology and sub-sector specialization), it provides a reasonable proxy to the capital-labor ratio within metropolitan regions. The human-capital labor ratio or average education per worker (*Education*) within a metropolitan area is obtained from the American Community Survey (2006) and measured as the percentage of the metropolitan population of 25 years and older with a bachelor's or graduate degree or higher. As our output variable is GDP, which equals the total production minus intermediate inputs, we do not take intermediate goods into consideration (see also Broersma and Oosterhaven, 2009). Moreover, as the agricultural and mining sector were excluded from our analysis we did not include the land-labor ratio, as only for these two sectors the acres of land can be considered an important input factor.

However, the main variables of interest in our research are the indicators related to the urbanization externalities and spatial structure. Urbanization externalities are captured by the variable *Metropolitan Size*, which is measured as the size of the metropolitan population in 2006. With respect to urban spatial structure, we include both the degree of *Polycentricity* and *Dispersion* in our model. *Polycentricity* is measured by a size gradient, while *Dispersion* is measured as the percentage of people in the metropolitan area under observation living outside centres of more than 25,000 inhabitants. A more detailed account of the measurement of these variables was provided in Section 3. Finally, dummy variables based on the census divisions are included, which reflect eight broad geographic regions in the United States (New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain). These dummies attempt to control for unobserved heterogeneity across metropolitan regions, in particular differences in technology and price levels.

Table 2: Descriptive Statistics of Variables (N= 113)

	Mean	Std. dev.	Minimum	Maximum
<i>Labor Productivity (ln)</i>	11.3	0.197	10.7	11.8
<i>Capital-Labor Ratio (ln)</i>	11.9	0.10	11.7	12.3
<i>Education (ln)</i>	-0.621	0.404	1.650	0.417
<i>Metropolitan Size (ln)</i>	13.68	0.997	12.43	16.89
<i>Polycentricity (ln)</i>	0.551	0.577	-2.291	1.636
<i>Dispersion (ln)</i>	-0.769	0.425	-2.144	-0.124
<i>New England</i>	0.027	0.161	0	1
<i>Middle Atlantic</i>	0.071	0.258	0	1
<i>East North Central</i>	0.186	0.391	0	1
<i>West North Central</i>	0.088	0.285	0	1
<i>South Atlantic</i>	0.150	0.359	0	1
<i>East South Central</i>	0.177	0.383	0	1
<i>West South Central</i>	0.071	0.258	0	1
<i>Mountain</i>	0.088	0.285	0	1
<i>Pacific</i>	0.142	0.350	0	1

4.3. Endogeneity and Two Stage Least Squares Estimation (TSLS)

Although equation (3) can be estimated using conventional Ordinary Least Squares (OLS), this estimation technique does not account for the simultaneity between metropolitan size and structure and labor productivity. In the model specification, it is assumed that metropolitan size and spatial structure have an effect on metropolitan labor productivity. However, the causality of this relationship is far from clear. On the one hand, agglomeration is often associated with a number of benefits such as labor market pooling, accessibility to intermediate goods, knowledge spillovers, and proximity to consumers, which in turn would augment productivity. On the other hand, firms may also be attracted to economically dense areas because of the presence of higher productivity levels (Rosenthal and Strange, 2004). In other words, agglomeration can be regarded as both a cause and consequence of labor productivity. Likewise, urban spatial structure may be regarded as a consequence rather than a cause of labor productivity growth. High land and real estate prices in combination, driven by high levels of labor productivity in city centers, may drive out firms out of the CBD into suburbs and to other places in the wider metropolitan region. In this case, it is not spatial structure that directs urban performance, but urban performance that directs spatial structure.

Not accounting for simultaneity can lead to inconsistent estimates as it violates one of the underlying assumptions of OLS, namely that the independent variables are uncorrelated with the disturbance term of the dependent variable. In other words, the independent variables should not be affected by the dependent variable. Probably the most common technique to deal with this (potential) simultaneity bias is to isolate the effect that runs from agglomeration and urban spatial structure to labor productivity by means of a two stage least squares (TSLS) estimation (see also, Ciccone and Hall, 1996; Ciccone, 2002; Combes et al., 2008). In order to do so, we need instruments, or variables that are correlated with the endogenous independent variables but not with the dependent variable. Hence, they should be 'relevant', but at the same time 'exogenous'. Based on Ciccone and Hall (1996), we use five historical variables that are not related to labor productivity

today, as production was 70-150 years ago organized in a very different way than nowadays, but did significantly contribute to today's metropolitan size and spatial structure:

1. The metropolitan population in 1950.
2. The degree of polycentricity in 1950, measured by a size gradient.
3. The degree of dispersion in 1950, measured as the proportion of the metropolitan population living outside places of 25,000 inhabitants or more.
4. Presence or absence of a railroad in the metropolitan region in 1880 (Stover, 1961).
5. Agricultural land use, measured as the density of employment in agriculture outside the urban areas.

The 1950 variables are constructed exactly similar to our 2006 variables. It is assumed that the presence or absence of railroads in 1860 was not driven by modern productivity differences (Ciccone and Hall, 1996), but are important in explaining agglomeration at the end of the 19th century and the development of other places in the early 20th century (Van der Laan, 1998). Finally, more extensive agricultural land use outside the urban areas, increases relative land rent as competition for land intensifies (Brueckner, 2001). This in turn, slows down the development of urban sprawl compared to metropolitan areas in which non-urban land is relatively cheap. Agricultural land use is however not related to our dependent variable as this sector was excluded in the measurement of the labor productivity of metropolitan areas.

As its name already suggests, TSLS estimates the model in two stages. In the first stage, the instrumental variables are regressed on the endogenous independent variables. In the second stage, the predicted values for the endogenous variables are put into the original regression equation, in which labour productivity is the dependent variable. Although the instruments are only used in the first stage, the control variables (capital-labor ratio, human-capital labor ratio, census area dummies) are included in both stages.

5. Empirical Results

5.1. Testing for endogeneity of metropolitan size and spatial structure

Although there may be a problem of recursive causality from a theoretical point of view, this does not necessarily mean that there is a problem from an econometric point of view (Combes et al., 2008). If indeed the independent variables of interest can be treated as exogenous, then OLS, which is a more efficient estimator, should be preferred over the TSLS estimator (Wooldridge, 2006). Hence, it is useful to assess whether there is indeed a correlation between the suspicious independent variables and the disturbance term. In order to conduct such a test, the instruments need to fulfil two general conditions: they should be relevant (not weak) and valid (exogenous). In other words, they should be correlated with the endogenous independent variables and uncorrelated with the disturbance term of the dependent variable. Not accounting for the irrelevance and invalidity of instruments can lead to biased, inconsistent and inefficient results.

Table 3 shows the test results on the relevance and validity of the instruments as well as the endogeneity of metropolitan size and structure. The endogenous variables were tested both separately and simultaneously. In other words, we ran three regressions in which we instrumented metropolitan size,

polycentricity or dispersion and one regression in which we instrumented the three variables simultaneously. Note we included more instruments than endogenous independent variables in each specification in order to conduct an overidentification test to assess the validity of the instruments. To evaluate whether an instrument is relevant, we rely on the Anderson canonical correlation, Cragg-Donald F-statistic and Shea Partial R^2 . The Anderson canonical correlation statistic is significant in all four specifications, meaning that the instruments used in these specifications are adequate to identify the equation. The Cragg-Donald F-statistic tests whether we face a weak-instrument problem. In this, a set of instruments is defined as weak if the bias of the TSLS estimator, relative to the bias of the OLS estimator, exceeds the threshold of 10% (Stock and Yogo, 2005) at the 5% confidence level. As can be obtained from Table 3, this is the case for all specifications as the value of the Cragg-Donald F-statistic exceeds the critical values provided by Stock and Yogo (2005). These results are reinforced by the Shea partial R^2 statistic, which is reasonable high for all specifications. In particular, metropolitan size appears to be well instrumented.

With respect to testing the validity of the instruments, both the Sargan and Basmann test indicate whether the instruments for metropolitan size and spatial structure are uncorrelated with the disturbance term. As these overidentification test statistics are for all four specifications not significant, we cannot reject the null hypothesis that the instruments are uncorrelated with the disturbance term of the dependent variable and can be considered valid.

Finally, we test whether the included endogenous independent variables are also econometrically endogenous. In this, the Wu-Hausman F-test and Durbin-Wu-Hausman Chi-Square test assess the null-hypothesis that the instrumented variables are exogenous by comparing the TSLS estimates with the OLS estimates. From these tests it can be obtained that metropolitan structure in terms of polycentricity or dispersion can be treated as exogenous. In line with Lee and Gordon (2007), this is not surprising because 'spatial restructuring is a long-term process'. However, for the specification in which metropolitan size is instrumented the Durbin-Wu-Hausman test rejects the hypothesis at a 5% confidence level ($p=0.049$) the estimation of this equation using the OLS estimator would not yield inconsistent results. Examining the specification with multiple endogenous regressors, we cannot reject the null-hypothesis that metropolitan size, polycentricity, and dispersion are exogenous. As both the Wu-Hausman F-test and Durbin-Wu-Hausman Chi-Square test indicate that there is no evidence for an endogenous relationship between labor productivity and metropolitan size and structure, OLS estimation should be used, given the fact that our instruments are relevant and valid and OLS more efficient. However, we test for robustness of our results by comparing the OLS estimates with the estimates from the TSLS specification in which only metropolitan size is treated as endogenous.

Table 3: First stage results of TSLS regressions on metropolitan labor productivity

Instrumented	Metropolitan Size	Polycentricity	Dispersion	All
Instruments	Population '50 Railroad	Polycentricity '50 Railroad	Dispersion '50 Agr. land use	Population '50 Polycentricity '50 Dispersion '50 Railroad Agr. land use
<i>Relevance</i>				
Anderson canon. corr.	82.90**	35.27**	37.25**	35.77**
Cragg-Donald F-test	134.9**	22.24*	23.93*	6.68*
Critical value CD (10% relative bias)	19.93	19.93	19.93	6.06
Shea Partial R ²				
- Metropolitan size	0.73			0.76
- Polycentricity		0.31		0.35
- Dispersion			0.33	0.26
<i>Validity</i>				
Sargan statistic	0.06	0.01	0.01	0.87
Basmann statistic	0.05	0.01	0.01	0.88
<i>Exogeneity</i>				
Wu-Hausman F-test	3.47	0.89	0.09	1.37
Durbin-Wu-Hausman Chi-Square test	3.87*	1.02	0.11	4.65
<i>Summary Statistics</i>				
Observations	113	113	113	113
Regressors	14	14	14	14
Instruments	15	15	15	16
Excluded Instruments	2	2	2	5

5.2. Labor productivity, urbanization externalities and spatial structure

Model 1 in Table 4 shows the results of the OLS estimation of metropolitan size and spatial structure on labor productivity, controlling for capital-labor ratio, education and including census fixed effects. The Breusch-Pagan test indicates that the null-hypothesis that the residuals are homoskedastic cannot be rejected, while the Ramsey RESET test shows that we do not face an omitted variable bias problem. In general, the model fits the data well, explaining about two third of the variance in labor productivity across American metropolitan areas.

Turning to the main results, we find a positive and significant effect of the capital-labor ratio (elasticity of about 0.8) and no effect of the proportion of the workforce with a bachelor's degree or higher on metropolitan labor productivity. However, our main interest lies in examining the effect of metropolitan size and structure on urban performance. In line with the existing empirical work on agglomeration, we find a positive and significant effect of urbanization externalities on metropolitan labor productivity. A doubling of metropolitan size increases metropolitan labor productivity by about 10%. With respect to metropolitan structure, we find mixed results, in the sense that we find a positive and significant effect of the degree of polycentricity on metropolitan labor productivity, but no effect of dispersion. Based on the literature, we had assumed that dispersion would have a negative effect on labor productivity, but this is not the case. However, the effect of polycentricity confirms our theoretical assumption. An increase in polycentricity by 1%, increases the metropolitan labor productivity by 0.057%. This means that a situation in which the urban population spreads over multiple places in the

metropolitan region leads to higher labor productivity than the situation in which the urban population is concentrated in one large city in the metropolitan region. We will elaborate on this important finding in the concluding section.

Comparing the OLS and TSLS estimator (Model 2 in Table 4), it can be obtained that the urbanization externalities effect is about 20% less when estimated using TSLS (elasticity of 0.08), while the effect of the capital-labor ratio is larger. The parameter estimates of polycentricity and dispersion do not significantly differ across the models.

Table 4: OLS and TSLS on Metropolitan Labor Productivity (2006)

	Model 1 OLS	Model 2 TSLS^a
Intercept	11.27 (.033)**	11.27 (.033)**
Capital-labour ratio (ln)	0.783 (.022)**	0.928 (.022)**
Education per worker (ln)	-0.014 (.048)	-0.043 (.049)
Metropolitan population (ln)	0.100 (.017)**	0.081 (.018)**
Polycentricity (ln)	0.057 (.022)**	0.054 (.020)**
Dispersion (ln)	0.024 (.036)	0.024 (.036)
Census area dummies	YES	YES
Number of Observations	113	113
F-statistic	15.06	13.45
R ² / Centered R ²	0.66	0.66
Root MSE	0.12	0.11
Breusch-Pagan test	1.15	
Ramsey's RESET test	1.19	
**p<0.01, *p<0.05 Standard errors between parentheses; all non-dummy variables are mean-centered ^a Instruments used in the first stage of the regression for the endogenous variable metropolitan population		

Examining the interaction effects between metropolitan structure and urbanization externalities (Model 3 and 4 in Table 5), we only find a negative effect of the interaction effect between metropolitan size and polycentricity on metropolitan labor productivity. From this, it can be obtained that polycentricity enhances labor productivity within metropolitan areas, but this effect declines when the metropolitan areas becomes larger. To put it different, the interaction term can be interpreted as the fact that urbanization externalities are larger in monocentric cities. Or, put differently, the benefits of polycentricity hold more for smaller regions than for large regions (in terms of population). This also confirms our theoretical assumption. We will discuss the theoretical implications further in the next section.

Table 5: OLS and 2SLS on Metropolitan Labor Productivity (2006) – Interaction Effects

	Model 3 OLS	Model 5 TSLS ^a
Intercept	11.28 (.033)**	11.28 (.033)**
Capital-labor ratio (ln)	0.833 (.217)**	0.941 (.216)**
Education per worker (ln)	0.003 (.048)	-0.002 (.044)
Metropolitan population (ln)	0.087 (.017)**	0.073 (.018)**
Polycentricity (ln)	0.056 (.020)**	0.054 (.019)**
Dispersion (ln)	0.039 (.036)	0.043 (.036)
Metropolitan Size*Polycentricity	-0.061 (.020)**	-0.065 (.019)**
Metropolitan Size*Dispersion	-0.008 (.023)	-0.013 (.022)
Census area dummies	YES	YES
Number of Observations	113	113
F-statistic	14.59	13.67
R ² / Centered R ²	0.69	0.69
Root MSE	0.12	0.11
Breusch-Pagan test	3.19	
Ramsey's RESET test	0.22	
**p<0.01, *p<0.05 Standard errors between parentheses; all non-dummy variables are mean-centered ^a Instruments used in the first stage of the regression for the endogenous variable metropolitan population		

6. Conclusion and discussion

Recent theoretical interest of geographers has turned to postindustrial forms of urban agglomeration. The industrial image of a metropolitan region as being composed of an urban core and a rural hinterland is in many cases becoming obsolete and appears to be replaced by polycentric metropolitan regions that spread over larger territories, thereby including multiple cities that together constitute a metropolitan network of cities. The 'city' is becoming a regional phenomenon and calls have been made that this should also manifest itself in the study of agglomeration and agglomeration externalities as these seem to be associated also with wider, and more polycentric, forms of metropolitan agglomeration rather than being confined to a single urban core (Alonso, 1973; Scott, 1988; Richardson, 1995; Moolaert and Djellal, 1995; Storper, 1997; Coe and Townsend, 1998; Capello and Camagni, 2000; Kloosterman and Musterd, 2001; Parr, 2002; Phelps and Ozawa, 2003; Parr, 2004; Cheshire, 2006; Parr, 2008). Despite these calls, however, several of these scholars have brought forward that empirical research on agglomeration externalities in relation to the regional metropolitan urban system is rather non-existent, contrary to the more local scale of polycentric cities (e.g. Lee and Gordon, 2007). An important reason for this empirical deficit is that many existing economic analyses of agglomeration still depart from definitions of metropolitan areas that still correspond to industrial images of the city. Moreover, particularly in urban economics, spatial-structure is hardly an issue and often proxied by general indicators as just size or density, which, however, do not reveal much detail of the spatial structure within regions.

This paper takes up this empirical challenge by analysing how different spatial structures effect the development of agglomeration externalities in U.S. metropolitan regions in 2006 with over 250,000 inhabitants. Externalities were measured in terms

of labor productivity. The widest official delimitation of metropolitan regions was used (Combined Statistical Areas - CSA), and these regions were supplemented with the Metropolitan Statistical Areas that do not form part of such CSAs.

As regards spatial structure, we assumed that, next to size, two dimensions are important as these effect urban concentration within the region: 1) the monocentricity-polycentricity dimension that tells to what extent the urban population is concentrated in one, or spread over multiple urban places in a metropolitan region; and, 2) the centralization – dispersion dimension, which tells to what extent the metropolitan population is concentrated in centers at all. In addition to these indicators relating to spatial structure we controlled for the capital-labor ratio and human capital.

The theoretical discussion in this paper of urbanization externalities, spatial structure and labor productivity resulted in three assumptions about the relationship between a region's spatial structure and it's economic performance in terms of labor productivity.

1) Metropolitan regions with more dispersion, thus having a higher proportion of population not living in urban centres, perform worse in terms of labor productivity.

Whether a large part of the population is concentrated in urban centres or lives outside of these centers in the non-urban part of the metropolitan region was not found to influence labor productivity. Thus we found no evidence for the assumption of dispersion being harmful to labor productivity.

2) Metropolitan regions that are more polycentric show higher labor productivity.

This assumption rests on the idea that urbanisation economies 'regionalise' more than do 'urbanisation diseconomies', which appear to be confined to the city boundaries. We found a positive and significant direct effect of polycentricity on labor productivity, which seems to confirm this assumption. The more polycentric a region is, the higher labor productivity. This result appears to confirm ideas that agglomeration externalities spread over larger distances, and may interact in regions where multiple urban places, and hence, multiple sources of agglomeration externalities, are co-located. As such, it confirms that agglomeration economies need to be conceptualised in relation terms. Thus, as Phelps and Ozawa (2003) have put forward before, external economies are not confined to a single urban core, but instead, are shared among a group of functionally linked settlements. The latter appears the case in polycentric metropolitan regions. Hence, proximity to other urban places is beneficial (see Partridge et al., 2008)

3) The presence of urbanization externalities resulting in higher labour productivity in metropolitan regions is moderated by the extent of polycentricity

Metropolitan size tends to reflect the presence of urbanization externalities. It was found that polycentricity has an indirect effect on labour productivity as urbanization externalities are less in more polycentric regions. Put differently, the productivity gains of size diminish as the metropolitan region gets more polycentric. These results are in line with the conclusion of Meijers (2008a) who found that the more polycentric a region was, the less cultural, leisure and sports amenities were present. It also confirms the doubts raised by Parr (2004; 2008) and Bailey and Turok (2001) that the magnitude of urbanization externalities in a polycentric metropolitan region is less compared to a monocentric region. From a theoretical perspective, we cannot

expect that advantages based on density, proximity and the easy and sometimes unplanned exchange of information are equally present in a metropolitan region in which population is spread over multiple smaller cities as in one where the population is concentrated in a single large city.

However, it seems that the relative lack of urbanization externalities in more polycentric metropolitan region is offset against the relative absence of negative agglomeration externalities. Our findings on the interaction-effect also say that the positive effect of polycentricity decreases as the population size of the metropolitan region increases. An explanation could be that urbanization externalities increase disproportionately with size, and hence matter more for larger regions. Plausible reasons for polycentricity being more beneficial in smaller regions are that it is more easy to pool resources together in smaller regions, that governmental coordination between the cities in a metropolitan region finds a more fertile ground, that the need for interaction between the cities that make up a small metropolitan region is more urgent and more felt as otherwise necessary urban amenities such as for instance an airport or large theater could not be supported. Also, it might be that there is a better information exchange between cities in a smaller region about the opportunities for work, education and leisure in those cities. As a result, inhabitants of smaller polycentric regions might be required to adopt a more regional orientation to fulfil all their needs than inhabitants of larger cities, who, despite opportunities in nearby larger cities, still can fulfil many of their needs locally. Thus, an explanation worthy of further exploration is that cities in smaller polycentric regions are more functionally related than those in larger polycentric regions.

This paper is no attempt to find a specific 'optimal' spatial structure of metropolitan regions, and not only because such a quest would have many different answers depending on which actor's perspective would be adopted. Rather, our findings support Lee and Gordon (2007) who bring forward that there are many plausibly competitive urban forms and Parr (2008, p.3020) who states that 'in any event, successful economic development can take place under a variety of spatial-structure regimes'.

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Appendix A. Metropolitan areas included in the analysis.

In principle, we included all CSAs and MSAs not part of a CSA that had at least a total population of 250,000 inhabitants in 2006 and that were located in the U.S. continental states. Metropolitan regions are defined by the U.S. Office of Management and Budget (OMB), and the latest revised version (2007) of the 2000 definitional standards was used. A MSA contains a core urban area with a population of 50,000 or more. It consists of one or more counties and includes the counties containing the core urban area, as well as any adjacent counties that have a high degree of social and economic integration (as measured by commuting to work: 25% of employed residents working in the core) with the urban core. MSAs that are adjacent may be joined in order to form a Combined Statistical Area if the employment interchange is at least 25. Adjacent MSAs that have an employment interchange measure of at least 15 and less than 25 are combined if local opinion favors combination (OMB, 2000). There are also micropolitan areas that contain an urban core with a population of at least 10,000 but less than 50,000. These are not considered here, unless they form part of a CSA that is furthermore composed of at least one MSA.

Some regions had to be left out for other reasons:

- 1) CSAs are composed of metropolitan statistical areas and/or micropolitan statistical areas. Often, data was not available for micropolitan areas. In a limited number of cases, this meant that no reliable data for the CSA could be retrieved. The couple of CSAs of which more than 20% of their population was located in a micropolitan statistical area were left out for this reason. These were Charlotte-Gastonia-Salisbury, NC-SC; Fort Wayne – Huntington-Auburn, IN; and, Lexington-Fayette--Frankfort--Richmond, KY.
- 2) New Orleans was left out as the data appeared biased as a result of Hurricane Katrina.
- 3) As argued in the text, polycentric conurbations had to be left out. These include: Albany-Schenectady-Amsterdam, NY; Charleston-North Charleston, SC; Dallas-Fort Worth, TX; Davenport-Moline-Rock Island, IA-IL; Fayetteville-Springdale-Rogers, AR-MO; Hartford-West Hartford-East Hartford, CT; McAllen-Edinburg-Mission, TX; Miami-Fort Lauderdale-Miami Beach, FL; Minneapolis-St. Paul- St. Cloud, MN-WI; Palm Bay-Melbourne-Titusville, FL; Provo-Orem, UT; Sarasota-Bradenton-Punta Gorda, FL; Scranton—Wilkes-Barre, PA; Tampa-St. Petersburg-Clearwater, FL; Virginia Beach-Norfolk-Newport N., VA-NC.

List of metropolitan regions included in the analysis.

Albuquerque, NM*	Little rock - North Little rock - Pine Bluff, AR
Allentown-Bethlehem-Easton, PA-NJ*	Los Angeles - Long Beach- Riverside, CA
Appleton-Oshkosh-Neenah, WI	Louisville/Jefferson C.-Elizabethtown-Scottsburg, KY-IN
Atlanta-Sandy Springs-Gainesville, GA-AL	Lubbock-Levelland, TX
Augusta-Richmond County, GA-SC*	Macon-Warner Robins - Fort Valley, GA
Austin-Round Rock, TX*	Madison-Baraboo, WI
Bakersfield, CA*	Memphis, TN-MS-AR*
Baton Rouge - Pierre Part, LA	Midland-Odessa, TX
Beaumont-Port Arthur, TX*	Milwaukee-Racine-Waukesha, WI
Birmingham-Hoover-Cullman, AL	Modesto, CA*
Boise City-Nampa, ID*	Montgomery-Alexander City, AL
Boston-Worcester-Manchester, MA-RI-NH	Nashville-Davidson--Murfreesboro--Columbia, TN
Brownsville-Harlingen-Raymondville, TX	New York- Newark – Bridgeport, NY-NJ-CT-PA
Buffalo-Niagara-Cattaraugus, NY	Oklahoma City – Shawnee, OK
Canton-Massillon, OH*	Omaha-Council Bluffs-Fremont, NE-IA
Cape Coral-Fort Myers, FL*	Orlando-Deltona-Daytona Beach, FL
Chattanooga-Cleveland-Athens, TN-GA	Peoria-Canton, IL
Chicago-Naperville-Michigan, IL-IN-WI	Philadelphia-Camden-Vineland, PA-NJ-DE-MD
Cincinnati-Middletown-Wilmington, OH-KY-IN	Phoenix-Mesa-Scottsdale, AZ*
Clarksville, TN-KY*	Pittsburgh-New Castle, PA
Cleveland-Akron-Elyria, OH	Port St. Lucie-Sebastian-Vero Beach, FL
Colorado Springs, CO*	Portland-Lewiston-South Portland, ME
Columbia-Newberry, SC	Portland-Vancouver-Beaverton, OR-WA*
Columbus-Auburn-Opelika, GA-AL	Raleigh-Durham-Cary, NC
Columbus-Marion-Chillicothe, OH	Reno-Sparks-Fernley, NV
Corpus Christi-Kingsville, TX	Richmond, VA*
Dayton-Springfield-Greenville, OH	Roanoke, VA*
Denver-Aurora-Boulder, CO	Rochester-Batavia-Seneca Falls, NY
Des Moines-Newton-Pella, IA	Sacramento--Arden-Arcade--Yuba City, CA-NV
Detroit-Warren-Flint, MI	Salem, OR*
Duluth, MN-WI*	Salinas, CA*
El Paso, TX*	Salt Lake City-Ogden-Clearfield, UT
Erie, PA*	San Antonio, TX*
Eugene-Springfield, OR*	San Diego-Carlsbad-San Marcos, CA*
Evansville, IN-KY*	San Jose - San Francisco – Oakland, CA
Fayetteville, NC*	Santa Barbara-Santa Maria, CA*
Fort Collins-Loveland, CO*	Savannah-Hinesville-Fort Stewart, GA
Fort Smith, AR-OK*	Seattle-Tacoma-Olympia, WA
Fresno-Madera, CA	Shreveport-Bossier City – Minden, LA
Gainesville, FL*	South Bend-Elkhart-Mishawaka, IN-MI
Grand Rapids-Muskegon-Holland, MI	Spokane, WA*
Green Bay, WI*	Springfield, MA*
Greensboro--Winston-Salem--High Point, NC	Springfield, MO*
Greenville-Spartanburg-Anderson, SC	St. Louis - St. Charles- Farmington, MO-IL
Houston-Baytown-Huntsville, TX	Stockton, CA*
Huntsville-Decatur, AL	Syracuse-Auburn, NY
Indianapolis-Anderson-Columbus, IN	Tallahassee, FL*
Jackson-Yazoo City, MS	Toledo-Fremont, OH
Jacksonville, FL*	Tucson, AZ*
Johnson City - Kingsport - Bristol (Tri-cities), TN-VA	Tulsa-Bartlesville, OK
Kalamazoo-Portage, MI*	Utica-Rome, NY*
Kansas City - Overland Park - Kansas City, MO-KS	Visalia-Porterville, CA*
Killeen-Temple-Fort Hood, TX*	Washington-Baltimore-North. Virginia, DC-MD-VA-WV
Lakeland, FL*	Wichita-Winfield, KS
Lansing-East Lansing-Owosso, MI	Wilmington, NC*
Las Vegas-Paradise-Pahrump, NV	Youngstown-Warren-East Liverpool, OH-PA
Lincoln, NE*	

* Indicates MSA, otherwise: CSA.

Notes

ⁱ Only considering incorporated places of at least 5,000 inhabitants in 2006. In those cases where the second largest incorporated place in the metropolitan region did not meet this threshold, we used its actual size in order to be able to calculate a slope.

ⁱⁱ When looking at the rank-size distribution of cities in a city-region, a major issue is the question of how many cities should be included to base the regression line on. In general, sample size can be either a fixed number of towns, a fixed size threshold, or a size above which the sample accounts for some given proportion of a region's population (see also Cheshire, 1999). The latter has disadvantages for this research, as it will turn out that the number of towns included in the analysis is large for polycentric regions and small for monocentric regions. Hence, the number of towns comprising a given proportion of the population is in itself an indicator of mono- or polycentricity and applying such a measure twice would distort the picture. A fixed size threshold is equally inappropriate as in large and more densely populated regions a town of say 20,000 inhabitants may be insignificant, whereas it could be of great importance in a small or less populated region. It could be argued that a town ranked for instance third in a region is of importance in that region, despite its possible small size. Therefore, when measuring polycentricity, the sample size could best be based on a fixed number of towns. The question then is what this number should be. To meet this possible arbitrariness, we took the average of slopes calculated for different numbers of cities.