The impact of spatial organization on regional productivity in Europe

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ABSTRACT. *Within urban economics, findings related to the impact of external economies of urban size on productivity are increasingly complemented by external economies of spatial structure by the inclusion of dimensions such as polycentricity. It is then argued that hierarchically distributed cities within polycentric urban regions can mutually 'borrow' size and share the associated external economies in a regional context. Similarly, polycentricity has been gaining popularity among policy makers as it is assumed to benefit both intraregional cohesion as well as interregional competition. However, empirical evidence for the impact of polycentricity till date remains ambiguous due to diverging methodologies and conceptualizations. The aim of this paper is twofold, as it strives to harmonize its findings on the impact of spatial organization on productivity for European TL2 regions with the existing knowledge base – which is mainly US-based – while also introducing several measurement and estimation improvements. We predict regional total factor productivity with both ordinary least squares and two-stage least-squares models, and find that significant causal effects exist for both urban size and structure. While confirming the general finding within the literature that a larger urban size positively affects productivity, we also find that an interaction between size and polycentricity has a negative effect, which suggests an inability of regions consisting of polycentric city networks to substitute for the urbanization externalities associated with a single large city.*

1. Introduction

In a world where half of the population living in cities generates approximately 80 per cent of global output, urban dynamics play a pivotal role in the economic performance of regions at any scale (Dobbs et al., 2011). However, an increasingly urban character of a region does not guarantee a superior performance compared to its more rural or less citified peers. In Europe, cities like Berlin, Naples and Lille have struggled to keep up with their national averages when it comes to productivity, employment and income (OECD, 2006). Additionally, a general trend seen in Europe is that not the largest capital cities perform strongest, but rather the second-tier cities who at times report higher GDP growth rates (Dijkstra et al., 2013). Why is it that some urban regions home to populous capital cities fail to meet expectations related to economic performance and productivity levels, while other regions with seemingly less overwhelming urban powerhouses exceed them?

A possible explanation resides within a key success factor often stressed in the economic literature: the spatial organization of economic production. As urban entities grow in size, the way in which these are spatially organized has been found to influence the potential for growth and performance. Within the discipline of urban economics, an extensive stream of work has been devoted to examining the benefits associated with agglomeration economies, which arise when larger urban size and density enable productive clustering of firms and people (Glaeser, 2010), thereby profiting from three micro mechanisms: (i) *learning* through the interaction and diffusion of ideas between proximate firms (Marshall, 1890), (ii) the improved *matching* between a concentrated population of numerous firms and the inputs they require, and (iii) the *sharing* of indivisible facilities, large labor pools or gains from variety and the individual specialization of firms located in the agglomeration (Duranton & Puga, 2004).

Simultaneously, the negative consequences, namely agglomeration diseconomies, have received an increasing amount of attention as well, as they could explain the lacking performance of mega cities such as Berlin. A regional over-reliance on the infrastructure and capacity of a single city could risk disadvantages such as congestion, pollution and surging land rents and prices for localized labor (Fujita, Thisse, & Zenou, 1997). Instead, second-tier or smaller cities could attempt to attain the same agglomeration advantages while mitigating abovementioned risks through a different spatial structure in which their efforts and sizes are bundled. Together, multiple cities – i.e. multiple sources of agglomeration economies – interact and exchange production factors in order to attain higher levels of production. Reciprocity, knowledge exchange and unexpected creativity are assumed to enable dynamic synergies of interactive growth for cooperating networks of proximate cities linked via a good infrastructure (Batten, 1995). These combinations of cities are assumed to be able to tackle two seemingly conflicting issues: cohesion by enabling balanced regional development, and competition by allowing regions with multiple smaller cities to compete with mega-city regions (Meijers & Burger, 2010; Meijers & Sandberg, 2008).

This concept of polycentricity, its advantages relative to mega-cities and its implications for regional development have been received with great enthusiasm among policy makers and academic researchers, which has resulted in a multitude of studies conducted to test its premises. Consequently, a wide variety of definitions, scales and other operationalizations applied to different settings and contexts currently exists, which makes the clear delineation of a polycentricity study almost as important as its empirical components for a useful interpretation of its results (Meijers, 2008; Rauhut, 2017). In order to support decisions and policies on a regional scale larger than one viewing cities on a standalone basis, research on polycentricity has recently extended its traditional focus from the micro, intra-urban level to the 'meso' level of polycentric urban regions (PURs) or even the 'macro' level of (trans)national urban systems (Davoudi, 2003; Dieleman & Faloudi, 1998). However, the conceptualization of polycentricity at the regional inter-urban scale remains at early stages as empirical research is limited and the literature is consolidated to a far lesser extent than is the case for research on the micro level of polycentricity (Davoudi, 2003).

Momentum of the usage of a more regional, inter-urban approach has been increasing among regional development policy-makers as well economic researchers (Meijers & Sandberg, 2008). In contrast to the micro view, which helps to examine issues related to intra-urban dynamics and problematic city growth, a macro approach proves to be useful in the analysis of how regional agglomeration and network economies can be exploited. Of those recent studies in the academic field which have sought to explore the role of polycentricity in a more regional context, the focus has varied from the examination of polycentricity at multiple scales for OECD countries across the globe (Brezzi & Veneri, 2015), Italian or Dutch regions (Burger & Meijers, 2012; Veneri & Burgalassi, 2012), and US metropolitan areas (Meijers & Burger, 2010). However, truly unambiguous empirical support for polycentricity-oriented policies remains lacking from an academic standpoint, especially when looking at the European situation. This is particularly striking considering the fact that polycentricity has grown to become a crucial element in "all key EU level strategic documents on territorial development" (ESPON, 2017, para. 3). The reliance on polycentricity could therefore be problematic considering the equivocal empirical support it has so far received.

In light of all of the above it becomes apparent that it is not only important to empirically improve our understanding of the influence of polycentricity and spatial organization at the regional level, but also to reconcile it with our existing knowledge base. Building upon previous work on external economies of size and structure, this paper's primary objective is to do exactly that. By using a methodology comparable to that of the US study conducted by Meijers and Burger (2010) and analyzing polycentricity on the same regional scale as Brezzi and Veneri (2015), we aim to find empirical relations between spatial dimensions and productivity that allow comparison with other studies. Besides harmonizing our findings with existing research, we also introduce several innovative additions. Notable methodological improvements are the quantification of the effects of spatial factors on productivity in terms of total factor productivity (TFP), isolating the causality of these effects via an instrumental variable (IV) strategy, and relating these results to the appropriate context given the scale-dependencies inherent to research of polycentricity. Moreover, our findings concern a highly topical issue, namely that of optimizing the spatial organization of the steadily growing urban areas in Europe.

The remainder of this paper is organized as follows. An overview of the economic theory and empirical research describing the relationship between spatial organization and productivity is given in section 2, upon which three testable hypotheses are formulated. Section 3 sets out the operationalization and econometric method used to test these hypotheses, describing the measurement of the spatial dimensions and how these are incorporated into our econometric model. Next, section 4 discusses the data and variables used to quantify the econometric model. The empirical results are subsequently presented in section 5, after which section 6 concludes this paper with a discussion of its main findings and implications.

2. Theoretical Background

2.1 Urbanization externalities

The onset of globalization has provided economic actors – both businesses and individuals – with the opportunity to pursue what is best for them in an increasingly global playing field. In order to explain the effects of urban dynamics on regional economic performance, a great deal of empirical work within urban economics has centered on the role of diverging spatial features. Theoretical and empirical work within urban economics and regional science has typically focused on agglomeration economies, which affect firms mainly through two different channels. First, localization externalities represent a channel that only reaches firms within specific industries and not all of them (Graham et al., 2010; Puga, 2010). Alternatively, urbanization externalities are passed on to all firms within a specific region and represent external economies arising from size or density specifics of urban regions (Ciccone, 2002; Graham et al., 2010; Rosenthal & Strange, 2008).

Notable externalities resultant from a higher degree of urbanization could be a well-developed infrastructure, a common labor pool, R&D facilities, universities and other institutions accommodating increased economic performance (Isard, 1956). Furthermore, the diverse industry mix in such areas is likely to bring about firm interaction, generation, application, modification and recombination of ideas and applications across sectors (Van Oort, 2004). This positive relation between urbanization externalities and productivity has been well-documented in the empirical literature and was commonly found to be significant, but a flipside of the size coin also exists. A higher degree of urbanization could damage productivity levels through unfavorable urbanization diseconomies such as pollution, crime, or increased production factor prices (Meijers & Burger, 2010). Nonetheless, we believe that the benefits associated with urbanization externalities outweigh the disadvantages linked to its diseconomies, which inclines us to formulate our first hypothesis.

H1 *Urbanization externalities in the form of a larger urban population positively affect regional productivity.*

2.2 Scales and perspectives for polycentricity and spatial analyses

This paper strives to provide additional insights into the relationship between spatial dimensions and productivity while relating them to the appropriate scales and definitions. The importance of doing so becomes evident when viewing the abundance of different methods used in the economic literature going hand-in-hand with a stream of literature aimed at harmonizing these differences. Eventually, a clear operationalization will make it possible to interpret the key takeaways based on our results within the right context. Among the spatial dimensions comprising the main focus of this paper, the dimension that is most clouded by its diverging operationalization within urban economics is that of polycentricity (Meijers, 2008; Rauhut, 2017). In order to ensure methodological clarity and comparability with regards to polycentricity, this section discusses the possible ways in which it can be operationalized and the eventual approach chosen for this paper. Consequently, the careful operationalization of polycentricity is the guiding principle for the way in which this paper estimates the effect of the three different spatial dimensions on productivity, and will be discussed in this section.

Over the years, the multitude of urban centers as an important dimension in analyzing economic performance of urban regions has been described by a diverse range of explanatory concepts, such as ‘multi-core city regions’ (Westin & Östhol, 1994), ‘network cities’ (Batten, 1995), ‘city networks’ (Camagni & Salone, 1993; Glaese et al., 2016), and ‘polynucleated metropolitan regions’ (Dieleman & Faludi, 1998). Progress within the field is likely to have been hampered by the disparities between conceptual frameworks (Meijers, 2005). In recent years, significant effort has been directed at a conceptual convergence of such frameworks through the use of a monocentric-polycentric dimension, with fruitful empirical research often as a result (Burger & Meijers. 2012; Liu et al., 2016; Meijers & Burger, 2010; Zhao, Derudder, & Huang, 2017).

Still, two aspects are known to vary across studies using the same monocentric-polycentric dimension. Firstly, a large deal of confusion arises from the scale-dependent interpretation of the concept (Burger, Van der Knaap, & Wall, 2014). Within spatial economics, three main scales tend to be used for the analysis of polycentricity, each with interchangeable labels. At the most local level, the micro or intra-urban scale views individual cities as polynucleic urban structures with an internal hierarchical distribution of nuclei on their own (Rauhut, 2017). The macro or national scale is located at the other end of the spectrum and analyzes the spatial structure of entire national urban systems, while it is also occasionally extended to the transnational or global level (Brezzi & Veneri, 2015; Dieleman & Faludi, 1998). In between these two, the meso, regional or inter-urban scale focuses on PURs consisting of spatially and historically distinct cities with an assumed interaction between them that may influence agglomeration externalities (Kloosterman & Musterd, 2001). It is argued that studying agglomeration externalities at the regional scale is especially sensible when viewing the external economies associated with agglomeration externalities in such relational terms (Meijers & Burger, 2010). Furthermore, the sphere of influence of metropolitan areas has increasingly regionalized in recent decades due to the strong growth of these areas, which emphasizes the importance of a regional scale for a comprehensive analysis of their impact on productivity (Brezzi & Veneri, 2015). Taking into account the above, this paper therefore focuses on the regional scale for its analysis of polycentricity, while the effects of the other two factors of size and dispersion are also quantified and estimated on that particular scale.

Second, studies of polycentricity have been known to approach it from two different but greatly related perspectives. The morphological perspective tends to focus on a region’s balanced development through the internal characteristics of urban centers, such as their distribution and size. On the other hand, functional polycentricity analyzes the way in which the urban centers "organize the rest of the territory by supplying the functions that shape the territorial hierarchies" (Brezzi & Veneri, 2015, p. 1131). On the regional scale, the morphological perspective equates polycentricity with the balanced distribution of a region's city cores in space, while the functional perspective links it to a "balanced, multidirectional set of relations" (Burger & Meijers, 2012). Opting for a functional approach would entail the inclusion of more complex mutual linkages between the urban nuclei. In turn, the effect of these linkages on regional TFP would be harder to isolate and would require data that is currently lacking. The choice for a morphological approach does not only ensure comparability with morphological studies of regions like Meijers and Burger (2010) for the US or Brezzi and Veneri (2015) for OECD member states, it is also more warranted given the goal of this paper: analyzing the impact of urbanization externalities and spatial organization on TFP within the boundaries separating the European regions in our sample.

2.3.1 Spatial structure – Polycentricity

Despite the popularity of external economies of scale as the main explanatory factor for economic performance within the literature, it should not be viewed as a predictor of productivity differences from a spatial perspective (Anas, et al., 1998). The evolution of cities in terms of their size distribution does not follow a fixed spatial pattern in practice but tend to be very different across urban areas, as some evolve into singular mega cities while others include a collection of nearby cities (Meijers & Burger, 2010). More modern streams within urban economics therefore assume the spatial structure of urban networks to go beyond a single well-defined core. Linkages and interactions between sub-components of urban networks affect economic processes, taking into account the importance of urban centers in areas at a widening geographical scale (Burger & Meijers, 2012; van Oort, Burger, & Raspe, 2010). As such, adjacent member cities and their populations of firms and individuals could benefit from mutual spillovers and supply streams, thereby exploiting the 'borrowed size' from their neighbors (Alonso, 1973; Glaeser et al., 2016). The applicability of the notion of 'borrowed size' varies across urban regions dependent on spatial structure, as those with a higher number of urban centers are likely to rely more on interactive processes between them, compared to monocentric regions comprising of a single mega-city. Similarly, the agglomeration disadvantages such as congestion, pollution and fierce competition for production factors are likely to be more of an issue in highly concentrated, individual metropolitan cities and less so within urban networks consisting of multiple scattered but related nuclei (Meijers & Burger, 2010; Parr, 2002).

Notable differences in the degree of polycentricity have been found for US metropolitan areas, which often tend to display strong hierarchical features due to the traditional American urban development pattern. Instead of an emergence of multiple city cores, growth of the urban population in the US typically occurs by forming suburbs around a main city center that includes a central business district where the economic activity is mainly concentrated (Hou, 2016; Lee, 2007; Duranton & Puga, 2004). As a result of this, it seems that only some of the most polycentric metropolitan areas in the US truly qualify for the polycentric label, while the majority of these metropolitan areas ranks somewhere in between monocentrism and polycentrism (Meijers & Burger, 2010). In contrast to the relatively more moncentric outlay of urban regions in the US, the European urban population is mainly living in small and medium-sized cities (Meijers, Burger, & Hoogerbrugge, 2016).

The varying spatial urban structures characterizing the two continents has been proposed as one of the explanations for the so-called 'transatlantic productivity gap', which pertains to the diverging relative productivity levels resulting from a slowdown and acceleration of productivity in Europe and the US, respectively (Ortega-Artilés, 2012). Regions with a reliance on a single large city generally tend to be less abundant, more populated and more sectorally and structurally diversified than regions with multiple smaller urban centers. This combination of a relatively larger scale and diversity is assumed to make regions relying on a single large city more able to profit from the knowledge-related advantages associated with the three micro-mechanisms of learning, matching and sharing that underlie agglomeration economies (McCann & Ortega-Artiles, 2015). European regions – consisting of relatively smaller urban centers – could therefore be less likely to reap the benefits of the proposed knowledge-related advantages.

Nonetheless, the heterogeneous institutional systems within Europe have led to more variation in such flows as well as that in urban structures compared to the US (Barca, McCann, & Rodríguez-Pose, 2012). The relatively more polycentric structure of European regions appears to work for its second-tier cities, which have been found to outperform their larger capital counterparts in terms of GDP growth rates (Dijkstra et al., 2013; Parkinson et al., 2012). As the frequently-stressed importance of agglomeration for growth holds less strongly for European urban regions, the spatial structure itself might be more of a relevant factor influencing economic performance, where higher productivity levels are not attained via interactions within city cores, but rather between them on an increasingly regional level (Glaeser, 2011; Meijers & Burger, 2010). We therefore still expect the degree of polycentricity to matter for productivity levels in European regions, as expressed in our second hypothesis.

H2 *A higher degree of polycentricity has a positive effect on regional productivity.*

2.3.2 Spatial structure - Urbanization externalities for polycentricity structures

Relations between urban centers (and their hinterland) can produce network externalities benefitting the competitiveness of and the cohesion within a region. These network externalities resulting from a polycentric structure are assumed to be shared by a group of multiple cores, which together form a regionalized urban entity (Meijers & Sandberg, 2008). However, these network externalities are only able to replace simple urbanization externalities to a limited extent (Boix & Trullen, 2007; Veneri & Burgalassi, 2012). Increased distances between separate city cores might entail logistical issues while negating advantages related to the interactions inherent to a singular dense and centered metropolitan environment (Parr, 2004; 2008). Evidence from the US situation from Meijers and Burger (2010) suggested that metropolitan economic performance benefits from increased polycentricity, while positive urbanization externalities diminished in more polycentric regions as these grow in size. It also appeared that especially the smaller urban areas profit the most from polycentricity – potentially because of better functional relatedness among smaller polycentric urban areas, compared to larger polycentric areas where city cores might be large enough to function on their own – but this required further research. Possible explanations for the diminishing returns to polycentricity as size increases is that a collection of proximate cities is not a perfect substitute for a single larger city (Meijers & Burger, 2010). As a means to take this potential interaction between polycentricity and size into account we formulate a third testable hypothesis, which expects an outcome similar to the US study. However, we consider the possibility that when a larger city is part of a region, the effect of urbanization externalities could dominate that of polycentricity and borrowed size. Therefore, hypothesis 3 is as follows.

H3 The positive effect of polycentricity on regional productivity diminishes as urbanization externalities increase.

2.4 Spatial structure - Dispersion

Following reasoning by Anas et al. (1998) as well as the methodology of our benchmark US study by Meijers and Burger (2010), spatial organization is believed to go beyond the size of urban areas and the hierarchical distribution between them. Dispersion reflects the extent to which the population of a region is localized outside of its urban nuclei, while polycentricity captures the extent to which the population within those nuclei – i.e. the non-dispersed population – is distributed among the urban nuclei. The degree of dispersion of a region's population across its territory comprises a third dimension that is likely to have an impact on productivity levels, as the dispersion of the regional population is likely to go hand in hand with a dispersion of economic productivity (Rossi-Hansberg & Wright, 2007). Thus, a high degree of dispersion not only indicates that a region is less agglomerated and therefore more unlikely to benefit from agglomeration economies, it also can mean that the dispersed urban population and economic production impede the efficient utilization of centralized production factors such as human capital (Rauch, 1993).

As mentioned by Meijers and Burger (2010), the dimensions of polycentricity and dispersion tend to be associated with each other in practice. Still, numerous exceptions were found in their US study to disprove that premise, and the same holds for our European sample where we also find a fairly low correlation of 0.151 between the two dimensions. Instead, several combinations between the two spatial dimensions can exist to reflect diverging spatial structures, as displayed in Figure 1. The lower left quadrant demonstrates that a relatively high degree of dispersion does not necessarily equate to a high degree of polycentricity, as the population might be scattered over the whole region with the exception of a single large urban nucleus. In addition to the spatial dimension of polycentricity, we include another testable hypothesis concerning the direct effect of dispersion, a spatial dimension for which we do not expect a specific interaction with size.

H4 *A higher degree of dispersion has a negative effect on regional productivity, independent of urban size.*

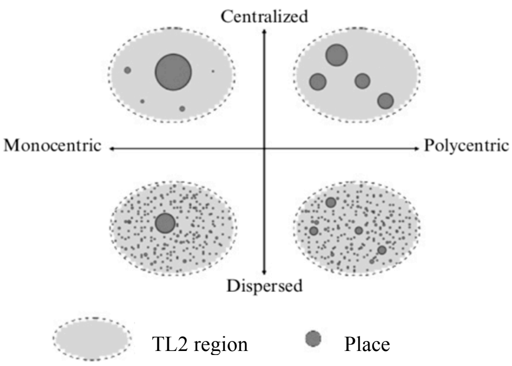

Figure 1. Dimensions of regional urban form (Meijers & Burger, 2010)

3. Operationalization and econometric method

3.1 Quantifying the impact of spatial dimensions

As mentioned in section 2.2, a careful delineation of the definitions and scales used in the analysis is an important first step in estimating the impact of spatial dimensions on productivity, especially in the case of polycentricity. The definitional ambiguity surrounding these spatial dimensions could lead to incomparable results, not only due to the fact that somewhat different concepts are being measured, but also because of disparities in the way in which these are measured (Rauhut, 2017). Consequently, ensuring consistency in the quantification of spatial dimensions once they are defined comprises the next challenge. For consistency's sake, our analysis follows largely the same strategy as the one deployed by Meijers and Burger (2011), dealing with three spatial dimensions: size, polcyentricity and dispersion. Similar to their US study, ours deals with morphological rather than functional measurements and therefore relies on the presence and distribution of urban populations within regions. As such, urbanization externalities are measured relatively straightforward by taking the size of the population living in all of the city cores of European regions.

3.1.1 Polycentricity – monocentricity

The measurement of polycentricity and dispersion also takes the urban population within regions as a starting point but requires further computation. Firstly, in order to express polycentricity as the balance and hierarchy between urban nuclei, a measure is chosen that makes an equitable comparison between regions possible. A frequently used estimator of the hierarchy among cities is the rank-size distribution, which calculates the slope of the regression line shown in Equation (1). Please note that the Equation shown here is based on Gabaix and Ibragimov's (2011) modification of the standard equation for rank-size distributions, where 1/2 is subtracted from the rank in order to correct for small sample bias, which helps in our case where there is only a limited number of European regions. In Equation (1), log rank – which denotes the ranking of a city core within its region based on its population – is regressed on log size, being the total population of a given city core within a region. The resultant coefficient of log size, expressed as β, reflects the degree of polycentricity / monocentricity: the steeper the line interpolating data, the larger coefficient β, the more uneven the balance between the cities included and the more hierarchical their distribution, meaning a more monocentric structure. Vice versa, a flatter line means a smaller coefficient, a more evenly spread and less hierarchical distribution of the urban population within a region and thus this region being more polycentric.

(1):

$$\ln(rank - 1/2) = \alpha + \beta \ln(size)$$

The fact that some regions are home to a larger number of city cores than others could already hint at a higher degree of polycentricity as the population is spread out over more nuclei (Burger & Meijers, 2012). To prevent such characteristics from affecting the outcome we follow recent studies and incorporate a fixed number of city cores in our computation of polycentricity (Brezzi & Veneri, 2015; Burger & Meijers, 2012; Meijers & Burger, 2010). According to Meijers (2008, p. 1320), basing the sample size on a fixed number of city cores is advantageous as "the extent of mono- or polycentricity is generally judged on the basis of the size and spatial distribution of just the handful of largest cities". The final degree of polycentricity is calculated based on the average of the rank-size distributions calculated for 2, 3, and 4 cities included. A few examples of the rank-size distributions with 4 cities included are given in Figure 2.1 and Figure 2.2, which show the fitted lines for West-Nederland (which is more or less equal to the Randstad area, the traditional showcase of a polycentric urban region) and Mazowieckie, a Polish region dominated by the large city of Warsaw. As expected, the fitted line of the rank-size distribution line of the Randstad area is relatively flat compared to that of Mazowieckie, reflecting a relatively higher degree of polycentricity for the Randstad region.

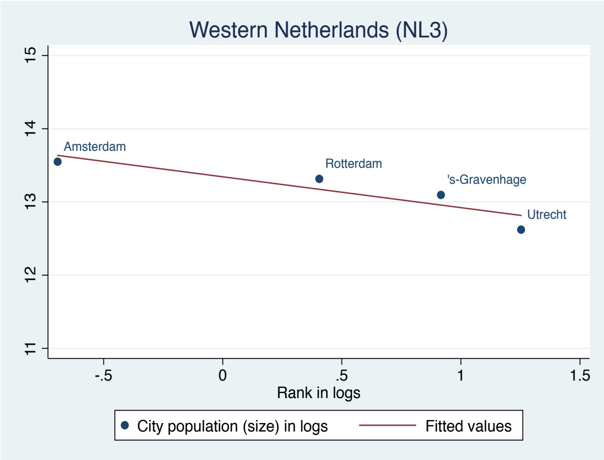

Figure 2.1: Rank-size distribution for Western Netherlands.

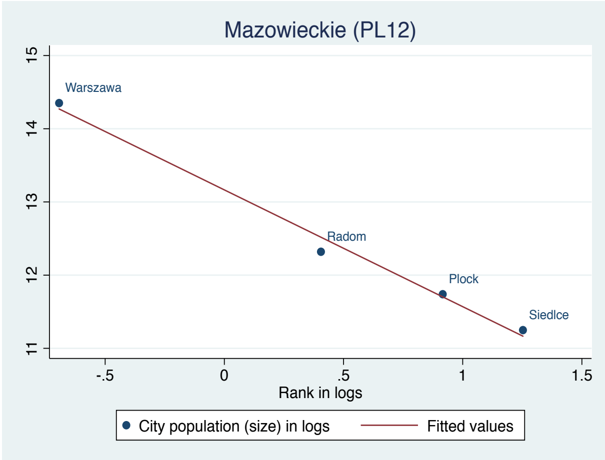

Figure 2.2: Rank-size distribution for Mazowieckie.

3.1.1 Dispersion – centralization

While the degree of polycentricity tells something about the hierarchical distribution of the urban population across a region's city cores, it does not reveal anything about the degree to which the population of a region is living within its city cores or rather outside of them. In accordance with Meijers and Burger (2010) we therefore include a supplementary spatial dimension reflecting the degree of dispersion – measured as the share of the regional population not located within its city cores – to test Hypothesis 4. The exact definition of city cores and what thus separates the dispersed and the centralized population from each other will be discussed in further detail in section 4.2.

3.2 Isolating the causality of spatial dimensions

A great deal of theoretical as well as empirical work within spatial economics has traditionally linked external economies associated with size or structure to productivity levels. However, only recently have studies stressed and investigated the potential bi-directionality inherent to this linkage, as regional productivity in itself could influence a region's growth or its spatial organization (Ciccone, 2002; Di Addario & Patacchini, 2008; Meijers & Burger, 2010; Rosenthal & Strange, 2008). As long as at least some production factors are mobile, higher productivity levels attracting firms and people could run very much in parallel with the traditional assumption within spatial economics that size leads to urban or industrial clustering benefiting productivity (Graham et al., 2010). Likewise, high land and real estate prices characterizing highly productive urban areas might cause people to move away from the main city cores to neighboring areas, which subsequently experience growth and clustering in their urban areas. Failing to control for the potentially simultaneous dynamics between productivity and spatial dimensions risks inconsistent estimates when using the Ordinary Least Squares (OLS) technique since one if its assumptions might be violated: the independent variables (reflecting the spatial dimensions) should be uncorrelated with the dependent variable's disturbance term (Meijers & Burger, 2010).

Ideally one would isolate the effect of spatial dimensions on productivity from the effect that could be running the other way around. As a means to achieve this isolated estimate, this paper relies on the two-stage least squares (TSLS) technique, which was not only used in the US benchmark study by Meijers and Burger (2010) but also for the majority of other studies estimating the impact of spatial dimensions on productivity (Graham et al., 2010). This technique requires the identification of instrumental variables that are (i) 'exogenous' in the sense that they are unrelated to the dependent variable (productivity today), and (ii) 'relevant' through their correlation with the endogenous independent variables (spatial dimensions). In order to use such an IV approach, data was collected with which we could construct three different instruments to be linked to each separate spatial dimension. A detailed explanation of the instrumental variables used in the IV analysis of this paper follows in section 4.4.

3.3 Other important factors

Apart from the hypothesized influences of the three main spatial dimensions, several other factors have been found to affect regional productivity as well in the field of spatial economics and should therefore be considered in our models. Firstly, human capital plays an important role in the production function of a region and should therefore be controlled for. The inclusion of human capital (H) into a model analyzing productivity gains can bear significant improvements in the accurate estimation of effects on total factor productivity, as was found by Maudos, Pastor and Serrano (1999) who empirically tested the frequently hypothesized link between human capital and economic growth in the economic literature (Baumol, Blackman, & Wolff, 1989; Engelbrecht, 1997). Furthermore, failing to control for human capital could lead to an upward bias in the outcomes of estimating the effect of agglomeration economies, as the time-variant quality of the labor force tends to be positively associated with the size of urban agglomerations (Melo, Graham, & Noland, 2009). An important element that also is frequently included in estimations of productivity in spatial economics is the quality and availability of infrastructure. Connectivity via infrastructural resources facilitates a smooth and efficient economic production within a region and represents a prime factor in the location decisions of firms (Garcia-López & Muñiz, 2010; McMillen & Lester, 2003; McMillen & McDonald, 1998).

Rapidly innovating and growing industries could display different productivity levels than their relatively more stable and traditional counterparts. Consequently, the industry mix– expressed as the dependence on high-growth industry sectors – has also been treated as a relevant factor influencing regional productivity and needs to be taken into account (Giuliano, Redfearn, Agarwal, & He, 2012). Lastly, macro-geographical characteristics related to climate and nature could contribute to further differences in productivity levels between regions (Meijers & Burger, 2010; Partridge, Rickman, Ali, & Olfert, 2009). Taking into account all of the factors mentioned above is imperative for a successful estimation of the effects of our three main spatial dimensions on productivity. The next section will dissect this paper's econometric model and how all of the relevant factors are reflected therein.

3.4 Econometric model

In order to test the four hypotheses of this study, a framework is needed to isolate the relationship between spatial dimensions and productivity. To make a comparison between estimated effects across continents possible, this paper relies on a different modification of the Cobb-Douglas production function as used in Meijers and Burger (2011). Their take on this function is as follows: in their paper on spatial characteristics and labor productivity in the US, the Cobb-Douglas function shown in Equation (2a) is the starting point. Here, the production factors of capital (K), labor (L), human capital (H), materials or intermediate inputs (M), and land (N) contribute to the combined output of all producers in the region, which are assumed to produce a single good. This composite good is denoted as nominal output Q. Finally, A captures the exogenous influences of elements not covered by the aforementioned production factors, such as the effects of urbanization externalities and spatial structure on efficiency and is therefore of particular importance for the hypotheses of this paper.

(2a):

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

Assuming constant returns to scale on production factors (κ + λ + θ + μ + ν = 1), Equation (2a) can be expressed in terms relating to output (or capital, land, etc.) per worker by dividing all terms with L, which results in Equation (2b).

(2b): $$\ln(Q) = \ln(A) + \kappa \ln(K) + \lambda L + \theta \ln(H) + \mu \ln(M) + \nu \ln(N)$$

All components of the multiplicatively formed Equation (2b) are logarithmically transformed in Meijers and Burger (2010) so that a linear stochastic form is achieved which yields a testable equation, as displayed in Equation (2c).

(2c): $$\ln(Q) = \ln(A) + \kappa \ln(K) + \lambda L + \theta \ln(H) + \mu \ln(M) + \nu \ln(N)$$

The origins of the Cobb-Douglas function trace back to a nationwide study of US manufacturing data, which was already collected on a national scale between 1899 and 1922 (Douglas, 1976). Valuable insights can be drawn from research on spatial structures in Europe – a continent known for its long-standing urban traditions – but a one-on-one comparison with a US study is somewhat unpractical. Detailed, comparable, historical data is scarce in the case of Europe with its many different countries and corresponding statistical offices. Only in recent years have forces been bundled to harmonize data and come to an extensive database comprising EU-member countries such as Eurostat. Due to these data limitations, this paper will test an alternative model for regional productivity while attempting to account for largely the same variables as the ones in Equation (2c).

The dependent variable used in the US study by Meijers and Burger (2010) measured labor productivity as the real GDP of a metropolitan area divided by the total number of jobs in a selected number of sectors. This measure thus reflected the value of production that was achieved with a single job in a given metropolitan area. Rather than predicting output per worker via the combination of production factors with exogenous influences such as spatial structure, the model in this paper captures factors influencing a region's TFP, which is defined as "the portion of output not explained by the amount of inputs used in production" (Comin, 2006, p. 260). As a result, the level of TFP reflects the efficiency and intensity with which inputs are put to use in production, and can even be argued to be a more accurate measure of productivity than one capturing output. Nonetheless, both dependent variables attempt to measure productivity levels: the main difference is that labor productivity captures the level of productivity related to a job for given levels of certain production inputs, and that TFP captures productivity levels regardless of the levels of the inputs. Although therefore highly comparable, the change to a TFP measure, if considered significant at all, can be seen as a methodological improvement. The computation of TFP is the result of predicting the residuals of Equation (3a).

(3a): $$\ln(GVA)_{ij} = \kappa \ln(K)_{ij} + \lambda \ln(L)_{ij} + y_i + \varepsilon$$

Where capital (*K*) and labor (*L*) together with year fixed effects *y* predict gross value added (*GVA*) for each region *j*. The residuals between the observed values and the fitted line are the observations per region for a variable representing total factor productivity. In turn, these residuals reflecting TFP are the dependent variable for the main model of this paper predicting regional productivity in European regions, which is show in Equation (3b).

(3b): $$\ln(TFP) = \theta_0 + \theta \ln(H) + \sum_j \theta_{j+1} \ln X_j + r_j + \varepsilon$$

Since the production factors of capital and labor are already incorporated in the computation of TFP itself, these are no longer explicitly included in the model. The remaining factors taken into consideration are in line with those used by Meijers and Burger (2010). *H* denotes human capital, the production factor that was not included in the computation of TFP, in the form of education. In order to account for exogenous influences on productivity beyond traditional production factors, a set of variables *X* with parameters θ supplements the model. Included in *X* are the spatial characteristics of size, polycentricity and dispersion, but also infrastructural connectivity and the emphasis on hi-tech employment in a region. Lastly, geographically bound differences such as climate and price levels could result in potentially moderating influences on the relationship between the factors mentioned above and TFP, which is why the European model also includes region dummy variables *r* to control for such forces. A more detailed explanation on how all of these variables are empirically constructed will follow in the next segment.

4. Data and variables

The empirical investigation of this paper is conducted on a cross-section of 168 regions spread out over 16 countries, predominantly those with a long-standing EU membership. While all of the data is collected at either the official EU statistical NUTS2 or NUTS1 level, regions are defined at the OECD territorial level 2 (TL2). The OECD classification utilizes the NUTS2 and NUTS1 levels in such a way that each TL2 represents regions in the first tier of sub-national government, while ensuring that regions are large enough to be the subject of an analysis investigating interregional dynamics where cities do not cross interregional borders (Brezzi & Veneri, 2015). Furthermore, TL2 regions account for similar geographic and demographic dimensions, which ensures a comparison as homogenous as possible (D'Agostino, Laursen, & Santangelo, 2012). Although several countries and regions not yet included in our analysis display interesting urban development patterns in reality, they unfortunately did not dispose of sufficient data across the variables included in this study or at the level at which the empirical analysis is conducted.[1] The descriptive statistics for all of our main variables are presented in Table 1. For a detailed overview of the countries and regions included in our sample please refer to Appendix A1.

Table 1. Descriptive statistics of variables (N = 168).

	Mean	Standard deviation	Minimum	Maximum
Total factor productivity (ln)	0.0138	0.552	-1.330	1.330
Education (ln)	3.249	0.293	2.568	3.942
Hi-tech employment LQ (d)	0.387	0.488	0	1
Southern Europe (d)	0.238	0.427	0	1
Northern Europe (d)	0.155	0.363	0	1
Eastern Europe (d)	0.226	0.420	0	1
Connectivity (ln)	1.615	0.431	0.191	2.303
Urban population size (ln)	13.16	1.058	10.83	15.91
Polycentricity (ln)	0.284	1.101	-1.041	4.063
Dispersion (ln)	-0.484	0.774	-5.896	-0.0603
1850 urban population size (ln)	4.628	1.202	1.386	7.790
1850 polycentricity (ln)	0.437	1.001	-1.013	3.183
Land area (ln)	9.431	0.956	5.081	11.45

a) All variables are 2010-2012 averages unless mentioned otherwise
b) Dummy variables are marked with a (d), all other variables in logs are marked with (ln)

[1] The countries with incomplete data from the Eurostat or the Urban Audit databases were Bulgaria, Croatia, Cyprus, Denmark, Estonia, Finland, Iceland, Latvia, Macedonia, Norway, Romania, and Switzerland. Regions excluded because of data limitations were those located on other continents or remote islands (e.g., Guadeloupe for France, the Canary Islands for Spain or the Azores for Portugal). Regions that had data available in the databases but did not include sufficient cities to calculate polycentricity between 2010-2012 were Valle d'Aosta (IT), Alentejo (PT), Norra Mellansverige (SE), and the Highlands & Islands (UK). Similarly, excluded regions with no polycentricity calculation possible in 1850 were Střední Čechy (CZ), Severozápad (CZ), Łódzkie (PL), Mellersta Norrland and Övre Norrland (both SE).

4.1 Total Factor Productivity (TFP)

As explained in the previous section on our model, TFP – the dependent variable of this study – represents the productive ability of a region regardless of the amount of inputs used in the process. Using TFP as a proxy for productivity enables meaningful conclusions to be made regarding the impact of spatial dimensions, as differences in TFP "account for most of the cross-country differences in per-capita income and TFP growth is identified to be the main driver of the long run increase in the standard of living" (Kumar & Kober, 2012, p. 15). Consequently, our results should be able to tell us something about the profound impact benefits or disadvantages of spatial characteristics in the long run. Our TFP measure was computed at the NUTS2 and NUTS1 level by regressing the gross value added in a region on the production factors of capital and labor as well as time-fixed effects, and subsequently predicting the residuals of this regression as in a discussion paper by Cortinovis and van Oort (2017). All variables included were log transformed in order to correct for the skewness towards high levels of the production factors. The computation of TFP was based on data from Cambridge Econometrics, in which (i) regional gross value added is reported, (ii) capital was estimated by using the perpetual inventory method on gross fixed capital formation variable, and (iii) labor was given as the number of hours worked by the regional population.

4.2 Spatial dimensions: size, polycentricity and dispersion

Constructing the variables needed to test the main hypotheses of this paper related to spatial structure required a process of multiple steps. In order to mitigate the risk of analyzing cities transgressing regional borders, a modular approach is chosen towards estimating the size of the cities falling within each TL2 region. We first collected data from Eurostat's Urban Audit project on 104,179 municipalities, which are defined at the Local Administrative Unit 2 (LAU2) level. Where applicable, a LAU2 contains a code linking it to a city if the unit falls within the boundaries of a core city. Additionally, for the purpose of the analysis focusing on morphological polycentricity in terms of urban cores, only city cores with a minimum threshold of 40,000 inhabitants are included, rather than greater cities or functional urban areas (FUAs). As such, cities remain limited to their unambiguously identifiable cores, rather than a collection of urban settlements that could encompass multiple city cores at once. The application of all these rules minimizes inconsistencies and biases potentially arising from larger cities like FUAs crossing TL2 boundaries (Brezzi & Veneri, 2015). Eventually, the total population of a city core is thus determined by aggregating the population of its LAU2 components for the TL2 region where the majority of a city core's population is located.

For France, Greece, Sweden and the UK this linkage between LAU2 and city cores proved problematic due to a lack of city core codes connecting the two, which is why we resorted to simply using non-modular aggregated data on city core populations from the Urban Audit project itself to supplement our dataset. The last available data from 2008 was chosen to replace missing observations for 2010, 2011 and 2012 for five of Sweden's thirteen cities. In the case of France, we choose to leave out city cores from the Urban Audit dataset which in our opinion do not qualify as standalone urban cores to be included in our polycentricity analysis: (i) federations of municipalities (*communautés de communes*), (ii) agglomeration communities (*communautés d'agglomeration*) being urban government structures, and (iii) newly founded suburbs being part of a larger city (*villes nouvelles*). Only in cases where a separate component of such structures exceeded the threshold of 40,000 inhabitants – the same lower limit being applied to all other city cores in the Urban Audit – did we include it in the dataset. The total population living in the city cores of a TL2 region constitutes the size variable capturing urbanization externalities.

After determining the number of people living in the 730 city cores in the sample, the next step was to compute the remaining spatial factors of polycentricity and dispersion. As mentioned in section 3.1.1, the computation of polycentricity relies on rank-size distributions estimating the size-based hierarchy of city cores within a region. Although the interpretation of a flatter line linked to a higher degree of polycentricity works well in the visual representation of figures 1.1. and 1.2, a larger coefficient of this line still reflects a higher degree of monocentricity. In order to make the interpretation of the impact of polycentricity on productivity more intuitive for interpreting the empirical results, an additional transformation of the rank-size coefficient β's was conducted in line with Meijers and Burger (2010). The negative β's resultant from Equation (1a) were made absolute and were subsequently inversed so that a larger coefficient ended up representing the opposite, namely a higher degree of polycentricity instead of monocentricity. Consequently, a value range from approximately 0 to 25 facilitated a logarithmic transformation so that the polycentricity variable would fit the requirements of the econometric model, where it was part of the logarithmic term $\theta_{j+1}\ln X_j$. Calculating dispersion was more straightforward: the size variable – representing the total number of people living in the city cores of a TL2 region – was divided by the total TL2 population as collected from Eurostat's NUTS2 and NUTS1 data to get the share of people living in a region's city cores. Next, this measure was inversed to get the share of people not living in the city cores as a proxy for dispersion.

4.3 Control variables

As section 3.3 explains, several other factors of a non-spatial nature are believed to influence total factor productivity as well. Human capital is represented in our dataset as the percentage of the active population (aged 15-74) with a tertiary education according to the International Standard Classification of Education (ISCED) developed by UNESCO. This classification harmonizes differences in national education systems, so that a tertiary education in this case represents both an academic as well as an advanced vocational or professional education in all countries (OECD, 2015). Apart from tertiary education rates data was also gathered to control for the infrastructural connectivity and accessibility of a region, as this could naturally affect the logistic efficiency and intensity with which a region can organize its production. As a proxy for this factor, a connectivity variable scored on a 1-10 scale from a PBL (2014) dataset was incorporated, where connectivity is a combination of road, airport and seaport connectivity.

Given the fact that the sample set covers 16 different countries, differences in the emphasis on technology within regional employment are potentially more locally pronounced than would be the case for a single country. Rather than controlling for this through the use of dummy variables for macro-geographical regions, as was done by Meijers and Burger (2011) for their sample set of US metropolitan areas, an additional dummy variable was included, equaling 1 when the hi-tech location quotient of a TL2 region exceeds 1. This location quotient – which reflects the concentration of hi-tech employment relative to the sample set average – is computed by (i) taking the region's total employment in modern industry and business services, (ii) dividing it by the region's total employment to get the region's share of hi-tech employment, and (iii) lastly dividing this share by the share of hi-tech employment in the sample set's total employment. A location quotient higher than 1 thus indicates that the emphasis on employment in hi-tech sectors within a region is stronger than the emphasis on hi-tech employment of all regions in our sample combined. As for climates, price levels, political systems and other disparities in exogenous total factor productivity bound to macro-geographical differences, the sample set is divided into four macro-areas – North, Centre, South and East – with comparable countries in these respects, in accordance with Broadberry and O'Rourke (2010).

4.4 Instrumental variables

Whereas the collection of comparable data across 16 countries posed somewhat of a challenge already, finding relevant and exogenous instruments needed for a TSLS estimation proved to be even more so. Similar to other studies, an instrument for size was used based on long-lagged population variables (Ciccone & Hall, 1996; Meijers & Burger, 2010). The historical population data was collected from Bairoch, Batou and Chèvre (1988), who developed a dataset with estimated population figures for European urban settlements from 800 to 1850 using national statistical yearbooks. Their data on 1,732 European settlements in 1850 was used to estimate size and polycentricity in the same way as the more contemporary 2010-2012 variables included in this paper's analysis. Size was calculated by aggregating the total population of a TL2 region's urban settlements in 1850, which would result in a reasonable estimate of the total urban population within a TL2 region, although prone to a potential measurement error faced by Bairoch, Batou and Chèvre (1988). Similarly, polycentricity was computed again by taking the average of the rank-size distributions for the 2, 3, or 4 largest urban settlements within a TL2 region, and subsequently taking the inverse of its absolute value.

Lastly, we could not rely on the same lagged population data for a reasonably exogenous and relevant instrument for dispersion, given the fact that no historical estimates for total TL2 populations were available. Alternatively, this last spatial dimension is instrumented through the use of contemporary data on total land area in square kilometers, a variable that is reasonably exogenous as it is largely historically predetermined (Ciccone, 2002). It can be argued that (i) the establishment of regional borders in the past and (ii) the absence of notable changes in a region's land area in recent times make it unlikely that land area is endogenous to our model, while it does predict regional dispersion patterns. This historical predetermination of regional land area becomes apparent when looking at the specific NUTS areas and their borders as defined by the EU member countries, of which almost the majority relies on long-standing divisions. For example, German *Regierungsbezirke* go back to Germany's unification in 1871 and Spain's *communidades autónomas* or Italy's *Regioni* are characterized by a strong regional identity and a relatively high degree of autonomy. It should be noted that instances also exist where TL2 regions have been shaped by more recently determined NUTS borders for administrative or statistical purposes. Consequently, these regions have a comparatively weak historical foundation, such as the 4 *Groups of Development Regions* constituting Greece, the 4 *Landsdelen* of the Netherlands, or the UK's division into 12 *standard statistical regions*, (Rodríguez-Pose, 1998). Whether NUTS boundaries reflect long-standing divisions of the land or not, the general aim of the European Union (EU) is to "ensure that comparable regions appear at the same NUTS level" based on population size so that "each level inevitably contains regions that differ greatly in terms of area, economic weight or administrative powers" (Eurostat European Commission, 2011, p. 7).

The problems that do arise from using the NUTS2 classification are mitigated through the usage of the OECD's TL2 classification. Peripheral or island regions at the NUTS2 level with relatively small populations are almost all excluded from the sample used in the analysis of this paper, or are aggregated into larger NUTS1 regions based on the OECD classification. Upon inspection, aggregating Belgian, Dutch, Greek and British regions to the NUTS1 level did not result in excessively large regional populations, but rather solved the problems related to comparatively small regional populations. Thus, with the equalization of population size as a main criterion, it is likely that the population of a larger region in terms of square kilometers is relatively more spread out than a counterpart with less land but a fairly comparable population size. Ciccone (2002) made a negative link between employment density and this increased spread due to a larger land area, but we assume the spread of the population to be positively correlated with our dispersion measure as the increased availability of land leads to less clustering and urbanization.

Given the interest of this paper in the interactions between spatial dimensions in addition to their standalone effects, instruments for the interaction terms are also required. Finding separate instruments for the interaction terms from the already scarce data at the NUTS level poses a significant challenge, but a valuable alternative could be a computation of instrumental variables based on the existing variables in our dataset. A method to construct such meaningful instrumental variables is to perform separate first-stage regressions which take the endogenous variables as the dependent variable, after which the predicted values from these regressions are saved as new variables. Subsequently, interaction terms can be created based on these predicted values, which can then be used as instruments for the endogenous interaction terms, as was done in Bloom et al. (2013). Here, the predicted values obtained from the first-stage regressions represent the extent to which the main instruments – size in 1850, polycentricity in 1850 and the average total land area from 2010 to 2012 – predict the endogenous variables of size, polycentricity, and dispersion for the 2010 to 2012 cross-section period. Subsequently the predictive power of these main instruments is reutilized when constructing interactions between the predicted values resulting from the first-stage regressions.

5. Empirical results

5.1 Basic results using OLS

Considering the interest in the effect of three different spatial dimensions on productivity, a clear picture on the individual contributions of these factors is very much desirable. As a first step towards isolating the effects of these factors, we present the results of the estimation of seven different models in Table 2. All these models estimate the effect of three spatial factors on regional TFP for the 2010-2012 cross-section period average, using the OLS technique and controlling for education, hi-tech employment, connectivity and macro-geographically bound differences. What separates them is the inclusion of specific spatial structure factors. Before moving on to the IV analysis, which attempts to establish a causal connection, we first present the OLS results here as a starting point. The numbers displayed at the top of each column in Table 2 represent the model specifications used for the estimations. Columns 1-3 thus display the results from the models containing only one of the three spatial dimensions, columns 4-6 show the results pertaining to models with combinations of two of the three dimensions, and the results from the full model including all three dimensions can be seen in the last column.

The results presented in Table 2 suggest several associations between spatial characteristics and regional productivity. First, the effect of size – measured as the log of the population living within the city cores of a TL2 region – is strongly positively associated with regional TFP and remains statistically significant at the 1% level when adding other spatial dimensions to the model. Turning to polycentricity, it can be observed that the sign of its coefficient is negative across all model specifications and only significant when controlling for size. This could be due to the fact that size is an important predictor which should be included in the model to increase its predictive ability. Regions with similar degrees of polycentricity but very dissimilar sizes of the urban population can score very differently in terms of productivity. As mentioned before in section 2.3.1, the external economies of structure associated with polycentricity could provide a substitute for urbanization externalities, which is why it is important to control for both types of external economies simultaneously in order to estimate their separate respective effects on productivity. Failing to control for size could thus lead to a wrongful estimation of the actual effect of polycentricity.

Table 2. OLS results for the effect on regional TFP (2010-2012) for models with 1, 2, or all 3 spatial factors.

VARIABLES	(1) Size	(2) Poly	(3) Disp	(4) S & P	(5) S & D	(6) P & D	(7) All 3
Education (ln)	-0.07	0.10	0.10	-0.17	-0.07	0.07	-0.17
	(0.10)	(0.12)	(0.13)	(0.10)	(0.11)	(0.13)	(0.11)
Hi-tech employment LQ (d)	-0.10	-0.02	-0.05	-0.10	-0.10	-0.04	-0.09
	(0.06)	(0.07)	(0.07)	(0.06)	(0.06)	(0.07)	(0.06)
Southern Europe (d)	0.03	0.19**	0.17**	-0.00	0.02	0.16**	-0.01
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
Northern Europe (d)	0.05	0.18***	0.15**	0.08	0.05	0.18**	0.08
	(0.08)	(0.07)	(0.07)	(0.08)	(0.08)	(0.07)	(0.08)
Eastern Europe (d)	-0.83***	-0.74***	-0.76***	-0.86***	-0.84***	-0.77***	-0.86***
	(0.09)	(0.08)	(0.09)	(0.08)	(0.09)	(0.08)	(0.08)
Connectivity (ln)	0.46***	0.55***	0.53***	0.46***	0.46***	0.53***	0.46***
	(0.11)	(0.10)	(0.10)	(0.10)	(0.11)	(0.10)	(0.10)
Urban population size (ln)	0.15***			0.17***	0.15***		0.18***
	(0.03)			(0.03)	(0.03)		(0.03)
Polycentricity (ln)		-0.04		-0.07***		-0.03	-0.07***
		(0.02)		(0.02)		(0.03)	(0.02)
Dispersion (ln)			-0.05		-0.02	-0.04	0.00
			(0.05)		(0.05)	(0.05)	(0.05)
Constant	-2.26***	-1.09***	-1.07***	-2.15***	-2.26***	-0.98**	-2.25***
	(0.36)	(0.38)	(0.40)	(0.37)	(0.40)	(0.41)	(0.40)
Observations	168	168	166	168	166	166	166
R-squared	0.73	0.68	0.68	0.74	0.73	0.68	0.74

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.2 Interactions between urbanization externalities and spatial structure

The next step in analyzing the impact of spatial dimensions on regional productivity is to see how these dimensions interact. Urbanization externalities could benefit a region's productivity differently dependent on its degree of polycentricity or dispersion. In order to test this, we add interaction terms between urbanization externalities – being size – and polycentricity and dispersion to the model. The results from these regressions are displayed in Table 3, where the first two columns display the outcomes for Model 8 and Model 9, each including one additional interaction term (Size x Polycentricity and Size x Dispersion). The column on the far right shows the results for Model 10 estimating the effects of both interactions at once and it is the final OLS model. As is shown in Table 3, size and polycentricity remain statistically significant predictors of regional productivity in a model where all three spatial factors are included. Upon the addition of interaction variables between the three factors, their standard errors and coefficients barely change. Furthermore, the interaction between size and polycentricity seems to be negatively associated with regional productivity, as its coefficient is statistically significant at the 1% level in both models where it is included.

By contrast, interacting dispersion with urbanization externalities does not yield any statistically significant results, indicating that the effect of dispersion does not depend on the size of the urban population. What is particularly notable in Table 3 is the fact that dispersion only appears to be positively associated with regional productivity when controlling for all spatial factors and their interactions with size at once. Upon inspection of the correlations between the variables included, the cause of this could be rooted in the high correlation between dispersion and its interaction with size, which is shown in the correlation matrix in Appendix A2. A reasonable degree of caution should thus be maintained when attempting to draw a meaningful conclusion based on the association observed in Model 10 in Table 3, especially given the fact that dispersion is insignificant in any of the other specifications. It further demonstrates the importance of isolating the effects of the spatial dimensions and the ability to infer a degree of causality, which will be discussed in sections 5.3.1.

Table 3. OLS results for models including interactions between the spatial factors and their effect on regional TFP (2010-2012).

VARIABLES	(8) Size x Poly	(9) Size x Disp	(10) Both interactions
Education (ln)	-0.22**	-0.15	-0.21**
	(0.10)	(0.11)	(0.10)
Hi-tech employment LQ (d)	-0.11**	-0.10	-0.11**
	(0.06)	(0.06)	(0.06)
Southern Europe (d)	-0.00	-0.01	0.00
	(0.07)	(0.08)	(0.07)
Northern Europe (d)	0.19**	0.07	0.18**
	(0.08)	(0.08)	(0.08)
Eastern Europe (d)	-0.88***	-0.87***	-0.88***
	(0.08)	(0.08)	(0.08)
Connectivity (ln)	0.49***	0.46***	0.48***
	(0.10)	(0.10)	(0.10)
Urban population size (ln)	0.17***	0.18***	0.18***
	(0.03)	(0.03)	(0.03)
Polycentricity (ln)	-0.10***	-0.07***	-0.10***
	(0.02)	(0.02)	(0.02)
Dispersion (ln)	0.02	0.05	0.07**
	(0.05)	(0.03)	(0.03)
Size x Polycentricity	-0.06***		-0.06***
	(0.02)		(0.02)
Size x Dispersion		-0.06	-0.06
		(0.06)	(0.06)
Constant	-2.05***	-2.37***	-2.18***
	(0.36)	(0.38)	(0.35)
Observations	166	166	166
R-squared	0.76	0.75	0.76

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In order to take a closer look at the interaction terms and their specific effect on regional productivity, we created graphs plotting the marginal effects of polycentricity and dispersion for given levels of size. Figure 3 shows the marginal effect of polycentricity and dispersion for given levels of urbanization externalities, where the two top panes represent the marginal effects of these interaction terms when including them separately and the bottom panes represent the marginal effects when including both interaction terms simultaneously. All of the included variables were mean-centered in order to make the interpretation of the graphs more intuitive. As can be seen from the graphs, the negative effect of polycentricity on TFP is statistically significantly for cases where urbanization externalities are higher: the shaded blue area – representing a 90% confidence interval (CI) – no longer covers the zero line when size (in logs on the x-axis) exceeds approximately -1. Similarly, for any given level of size, the negative effect of dispersion does not seem to be deviating from zero as the 90% CI keeps covering the zero line. This statistically insignificant effect seems to persist when using both interactions at the same time: only at the mean of size (where it is 0 in the graph) does the 90% CI reveal but a fraction of the zero line, which supports the limited significance of dispersion across our estimations.

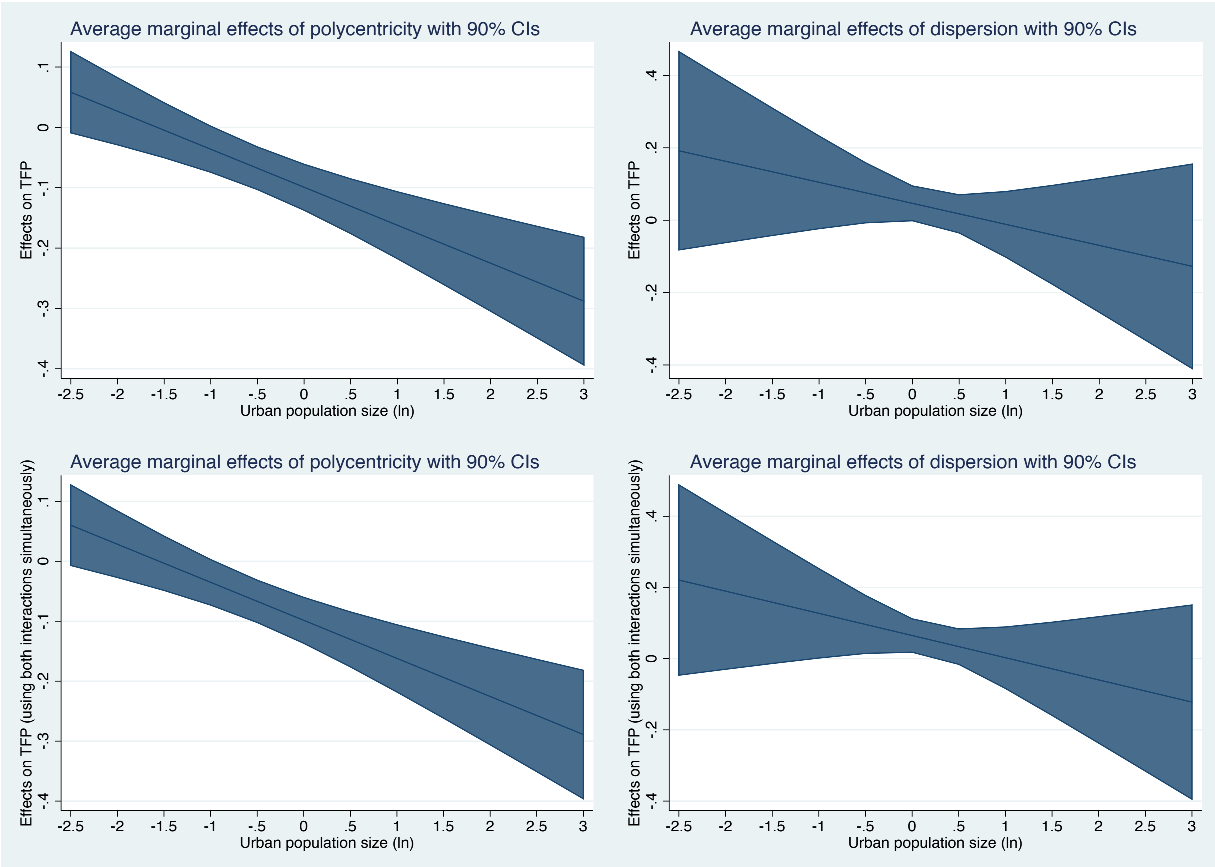

Figure 3: Marginal effects of polycentricity and dispersion for given levels of size. Top panels show graphs for individual interactions with size, the bottom graphs show the inclusion of both interactions simultaneously.

5.3.1 TSLS results – Establishing causation from spatial dimensions to productivity

While the OLS results presented above suggest several meaningful correlations between spatial dimensions and TFP in Europe, it is preferable to establish causality between the two in order to strengthen our understanding of the actual impact of spatial dimensions on regional productivity. Causation could not only run from our main independent variables – the spatial factors – to the dependent variable of TFP, but could also run in a reverse order. A higher level of productivity could attract more people to start living in urban centers, leading to larger sizes of the urban population, or regions to distribute their economic production and population evenly between these centers, which results in a higher degree of polycentricity. In order to make sure that the causality runs from the spatial factors to regional productivity instead of the other way around, we employ three instrumental variables in a Two-Stage Least Squares (TSLS) model. While section 4.4 justified the use of our three instruments from a theoretical stand, it is also necessary to test their power from an empirical perspective. This will be discussed in the next paragraph before we discuss the results of the coefficients.

Given the limited availability of useful instruments for European TL2 regions, the number of instruments we use in our estimations exactly equals the number of endogenous variables we are interested in. Unfortunately, this exact identification of our model rules out an overidentification test with which we can investigate the exogeneity of the instruments employed. We therefore have no other option than to rely on the theoretical and economic reasoning in sections 3.2 and 4.4 for excluding the endogeneity of our instruments. Nonetheless, testing the relevance of our instruments is possible by looking at the reported F-statistics from the first-stage regressions, which are reported at the bottom of Table 4 (for a detailed overview of the first-stage regression results please refer to Appendix A3). When used instruments are weaker, the bias of the IV estimator relative to that of the OLS estimator increases, which reduces the relative predictive ability of the IV model. Traditionally, the standard F-statistic derived from the first-stage regressions tests for the weakness of an instrument in a single endogenous variable model using a relatively simple expression. By adding additional endogenous variables to the model the expressions for the biases in the OLS and IV estimator change as well (Sanderson & Windmeijer, 2016).

Table 4. TSLS results for the effects of urbanization externalities (size), structure (polcyentricity and dispersion) and their interactions on regional TFP for the 2010-2012 cross-section period average.

	(11)	(12)	(13)
VARIABLES	All 3	Size x Poly	Size x Disp
Education (ln)	-0.45***	-0.43***	-0.42***
	(0.14)	(0.15)	(0.15)
Hi-tech employment LQ (d)	-0.14*	-0.20***	-0.13
	(0.08)	(0.06)	(0.08)
Southern Europe (d)	-0.18**	-0.10	-0.17*
	(0.09)	(0.09)	(0.09)
Northern Europe (d)	0.03	0.26**	0.03
	(0.09)	(0.11)	(0.09)
Eastern Europe (d)	-0.97***	-0.95***	-0.97***
	(0.09)	(0.10)	(0.09)
Connectivity (ln)	0.40***	0.47***	0.40***
	(0.11)	(0.10)	(0.11)
Urban population size (ln)	0.34***	0.27***	0.35***
	(0.05)	(0.05)	(0.05)
Polycentricity (ln)	-0.16**	-0.11	-0.18**
	(0.07)	(0.07)	(0.08)
Dispersion (ln)	0.05	0.03	0.14
	(0.07)	(0.07)	(0.17)
Size x Polycentricity		-0.16***	
		(0.04)	
Size x Dispersion			-0.11
			(0.18)
Constant	-3.29***	-2.57***	-3.44***
	(0.45)	(0.43)	(0.55)
1st stage F-stat – size	29.58***	28.59***	23.57***
1st stage SW F-stat – size	54.00***	42.81***	49.01***
1st stage F-stat – polycentricity	24.92***	18.70***	18.77***
1st stage SW F-stat – polycentricity	19.71***	15.39***	15.51***
1st stage F-stat – dispersion	6.75***	5.27***	8.38***
1st stage SW F-stat – dispersion	24.15***	22.50***	7.58***
1st stage F-stat – size x poly		8.51***	
1st stage SW F-stat – size x poly		30.35***	
1st stage F-stat – size x disp			6.19***
1st stage SW F-stat – size x disp			8.80***
Observations	166	166	166
R-squared	0.68	0.69	0.67

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In order to compare the relative biases in a multiple endogenous variable model we also report the Sanderson-Windmeijer F-statistic, which is better suited for models with more than one endogenous variable. All of the F-statistics reported for Model 11, Model 12, and Model 13 in Table 4 are sufficiently large and their p-values used for the weak identification test of excluded instruments are significant at the 1% level, which indicates that we can reject the null hypothesis that the model is identified.[2]

5.3.2 TSLS results – Causal linkages between spatial dimensions and TFP

After a review of the predictive ability of the IV estimators we can proceed to their results. The results in Table 4 prove to be robust with our OLS estimations: (i) the size of the urban population is a strong, statistically significant predictor of regional TFP, (ii) polycentricity has a statistically significant negative effect on TFP, and (iii) dispersion does not seem to have any significant effect on productivity. Moreover, the coefficients for the interaction terms are also robust to those observed in Table 4 and provide additional information about the dynamics of the effects of structural dimensions for given levels of urbanization externalities. Model 12 and Model 13 are the most detailed specifications with which we test the effects of the three spatial dimensions on productivity, and their results therefore the most important for our hypotheses. As in our OLS estimations, the negative effect of polycentricity on productivity turns out to apply especially for larger regions, as evidenced by the statistically significant negative coefficient of its interaction with size. The coefficient of the direct effect of polycentricity is no longer significant when controlling for its interaction with size, which suggests that the negative effect is predominantly present in regions with increased urbanization externalities. By contrast, the effect of dispersion in itself is not only insignificant, so is its interaction with urbanization externalities. This suggests that there is no mediating effect of size on dispersion, so that the effect of dispersion does not change for different levels of size. Further discussion of the results, their congruency with our hypotheses and their practical implications will be set out in the next section.

6. Conclusion and discussion

6.1 Main findings

Research in urban economics is characterized by a continuously innovating conceptualization of phenomena to be investigated. The rapid pace of change within these fields is only a natural by-product of the pace with which urbanization patterns across the globe are developing and urban areas are expanding. In recent decades, the traditional monocentric model of the city has been expanded with more polycentric alternatives, in order to capture the regionalization of urban areas and cities themselves. Networks of city cores are assumed to both compete and collaborate across space within these polycentric structures. External economies of structure could thus supplement external economies of scale as a predictor of regional economic performance and productivity. This paper has explored both the potential impact of scale as well as structure through an estimation of the effects of three spatial dimensions on regional productivity: size, polycentricity and dispersion. In order to add to the existing knowledge base, which is known for its varying measurements and methodologies to analyze these dimensions, we opt for a methodology similar to that of a US study by Meijers and Burger (2010). The particularly important difference in this case is a pan-European perspective, a continent known for its long-standing urbanization patterns and strong policy focus on polycentricity, but also a lack of clear, transnational academic research based on causal connections rather than associations.

[2] Please note that the first-stage regressions shown in Appendix A3 are in line with these results: when only including the three spatial dimensions, the first-stage coefficients of the instruments significantly predict their endogenous variable of interest. However, when including interaction terms, only the endogenous interaction term as a dependent variable is significantly predicted by all variables included in the first-stage regression. The insignificance of the first-stage coefficients predicting the spatial dimensions (and not the interactions) could be due to collinearity between the instruments, evidenced by the relatively high correlations displayed in Appendix A2.

In this analysis at the TL2 regional level, size was quantified as the total population living in city cores from Eurostat's Urban Audit project, polycentricity in the form of coefficients resultant from hierarchical rank-size distributions of city cores, and dispersion as the share of the regional population not living within the region's city cores. The dependent variable used as a proxy for regional productivity is TFP, which represents the efficiency and intensity with which inputs are put to use in production. Several other variables were also included to control for the potential influence of human capital, a regional emphasis on hi-tech employment, infrastructure and geographically bound exogenous influences on the regional economic performance. As a means to obtain results representing causal effects instead of associations, long-lagged or theoretically sound instrumental variables were collected to enable a TSLS estimation of the relation between the spatial dimensions and regional productivity. The results obtained from estimating several OLS and TSLS models translate into four main findings, which are discussed below.

H1 *Urbanization externalities in the form of a larger urban population positively affect regional productivity.*

Finding 1 *Size of the urban population is a highly significant predictor of regional TFP across all estimations.*

The first hypothesis tested the established postulation in urban economics that size matters, where the urbanization externalities that are developed by building up size are assumed to entail several advantages for productivity. Empirical evidence from numerous studies points in the direction that this is indeed the case, and it is also the most undisputed and robust result in all of the estimations in this paper. We therefore confirm the hypothesis that urbanization externalities – including, among others, a concentration of firms and production factors – positively impact the productive efficiency of European regions. While this result is probably the least surprising given the well-documented strong link between size and productivity in the economic literature, it provides the foundation for the interpretation of the results relating to the spatial structure dimensions of polycentricity and dispersion.

H2 A higher degree of polycentricity has a positive effect on regional productivity.

Finding 2 *Polycentricity does not have a significant direct effect on productivity.*

The results obtained to test the second and third hypothesis regarding polycentricity were not as consistent as those for size in the sense that the relevant coefficients were highly significant in each model specification. Findings 2 and 3 relating to the two polycentricity hypotheses – which appear interdependent – should therefore be discussed in light of each other in order to provide a complete picture of the potential dynamics at play. Firstly, the different OLS models with a variety of spatial dimensions included yielded a significantly negative coefficient as long as size was controlled for, which demonstrates the importance of controlling for external economies of scale in order to estimate the effects of external economies of structure. Second, a notable change occurs when switching from OLS to TSLS, as the significantly negative coefficient for the direct effect of polycentricity turns insignificant when including an interaction with size. Instead of using OLS results reflecting associations, or results from a TSLS model that could potentially be overlooking the dynamics between the effects of size and polycentricity, we therefore rely on the results from estimating Model 12 – which is the most elaborate and complete specification testing the functioning of the causal effect of polycentricity on productivity – to reject Hypothesis 2.

From a morphological perspective, a more evenly distributed urban population across city cores does not benefit productivity for the European regions in our sample. The direct effect of polycentricity on regional productivity is insignificant and thus disagrees with the US study by Meijers and Burger (2010), who found this effect to be significantly positive (on labor productivity). An explanation for this finding might reside in the great variation between European cities in terms of economic performance, which exists both among the group of larger as well as that of smaller cities. While some of the larger European cities such as Berlin perform worse than their smaller counterparts, small- to medium-sized European cities also tend face low or negative growth (Dijkstra et al., 2013). Consequently, the impact of hierarchical distribution between these city cores on regional productivity could be evened out due to this variation: the improved performance of one polycentric region including several well-performing cities might be offset by the relatively poor performance of another polycentric region, resulting in the coefficient of polycentricity not significantly pointing in a specific direction.

The strong effect found for size might be less prone to notable differences between larger cities offsetting each other, as several of the larger European cities tend to have a significantly positive influence on regional performance. Our outcome is similar to that of the OECD study by Brezzi and Veneri (2015), whose empirical results pointed in several directions, dependent on the scale of the analysis: polycentricity was found to be associated with higher GDP per capita at the national scale, though lower GDP per capita at the regional scale. The negative association based on OLS results appears consistent with theirs, but after applying several methodological changes aimed at improving the isolation of causal effects. When looking at the effect of polycentricity in causal terms, the precise way in which this spatial factor influences regional TFP becomes more apparent, which is discussed as Finding 3 below.

H3 The positive effect of polycentricity on regional productivity diminishes as urbanization externalities increase.

Finding 3 *Polycentricity negatively impacts regional productivity as size increases.*

The sequential method by which we isolate the effect of polycentricity on productivity proves to be fruitful as tweaking the specifications eventually leads to a better understanding of the forces at hand. In the final and most important estimation regarding polycentricity, Model 12 demonstrates that polycentricity in itself is not necessarily a significant negative predictor of productivity, but more so that it works hand-in-hand with size. The significantly negative coefficient of the interaction term we find is similar to that in Meijers and Burger (2010), with the only important difference being a baseline insignificant effect of polycentricity instead of the positive effect that they find. Instead of concluding that polycentricity works better for regions with smaller urban populations, and less so for regions with larger urban populations, the insignificant direct effect and significantly negative interaction term suggest that polycentricity does not work for urban regions with a relatively larger population in particular.

Consequently, one could conclude that polycentricity is an ineffective means to achieve higher regional productivity levels in the long run for expanding urban area. More specifically, a balanced morphological distribution of growth of the regional urban population could be less favorable for productivity compared to the case where the distribution is more hierarchical and centered in nature. This can be explained by the possibility that borrowing size is no longer an effective method to achieve urbanization externalities when the size of the regional urban population exceeds a certain threshold. An alternative line of reasoning is that size is a dominant force: polycentricity and the borrowing of size could be more important in regions with a lack of a relatively larger city, but is less effective in regions that do include one. Like Meijers and Burger (2010), we also conclude that – for European regions with similar urban populations – the urbanization externalities derived from multiple city cores do not substitute for those achieved with a structure relying on singular, monocentric mega-cities.

H4 *A higher degree of dispersion has a negative effect on regional productivity, independent of urban size.*

Finding 4 *Dispersion does not have a significant effect on productivity.*

Lastly, the estimation of the effect of dispersion did not yield any significant results as its effect was largely insignificant or ambiguous at best across all of our estimations. Whereas polycentricity seems to confirm the important role of spatial structure in explaining productivity differences, the dispersion dimension does not. European regions with a lower share of people living in urban centers do not appear to perform better or worse than their more centralized counterparts. As far as structure goes, it is thus the way in which the population is distributed across the city cores that matters, and not the way in which the population is spread between the city cores and the rest of regional area.

6.2 The wider context of our findings

Although we believe this paper makes a valuable contribution to the empirical academic research on spatial dimensions and productivity till date, much work remains to be done. The challenges ahead become apparent when setting out the limitations of our own study. Due to data restrictions, our paper conducts a cross-section analysis of the impact of spatial dimensions on regional productivity that is likely to be influenced by time-specific factors as well. For instance, many European countries experienced the 2010-2012 period as the economically turbulent aftermath of the 2009 financial crisis, with the gravity of the consequences varying across these countries (Hadjimichalis, 2011). Additionally, as stressed explicitly, the collection of comparable data poses a significant challenge when attempting an instrumental variable analysis since most of the long-lagged data sources do not go back far enough. European regional boundaries are only a relatively recent phenomenon and Pan-European data collection exercises are scarce or have to rely on a wide range of assumptions (Bairoch, Batou, & Chèvre, 1988). The instrumental variable analysis we performed on European regions while including multiple spatial dimensions represents a methodological improvement, but it can be optimized with additional instruments so that overidentification tests can be performed to test for the exogeneity of instruments. Furthermore, pan-European data collection initiative such as the Urban Audit are marked by frequent changes with respect to the way in which the variables included are defined and measured (Eurostat European Commission, 2017). Once such standards are set as definitive and universally accepted and used, a more accurate historical comparison of data and the usage of harmonized time-series data would become possible.

Apart from possible methodological improvements, our results should also be interpreted within the current paradigm of previous research. It is important to stress that our analysis focused on polycentricity from a morphological instead of a functional perspective, and should therefore be compared with similar morphologically-oriented studies (Brezzi & Veneri, 2015; Meijers & Burger, 2010). Therefore, the impact of polycentricity discussed in this paper should be interpreted as the effect of a balanced distribution between city cores on productivity, rather than the actual functional relations between the city cores affecting productivity. It could very well be that a different perspective on the concept leads to different results, as the morphological perspective could be overlooking the actual interaction or lack thereof within functional networks of city cores, which in turn affects regional productivity levels (Burger & Meijers, 2012). However, the flipside of analyzing polycentricity from a functional perspective in Europe remains a lack of sophisticated data at the European transnational level, as well as the possibility that externalities cross regional borders so that accurate measurement is made difficult. Overall, we support the many initiatives that can be undertaken to improve the understanding of the dynamics discussed in this paper.

In addition to our contribution to the economic literature on the relationship between spatial dimensions and productivity, empirical findings from this study could also serve to aid policy makers – especially those for the EU – in developing appropriate policies aimed at a morphological, spatial organization benefitting urban regions. As far as the European situation is concerned, a retrospective assessment of past EU policies based on convergence criteria demonstrates their lack of effectiveness and efficiency to face the challenges of today (Barca et al., 2012). The flaws associated with an aggregate, 'place-blind' approach call for growth and development intervention policies that are more 'place-aware', as effective intervention should take into account the varying factors at play across different urban regions. By taking explicit consideration for spatial factors and creating a contingency on the geographical context consisting of social, cultural and institutional characteristics, place-based policies are better able to exploit the local knowledge base and come up with the most appropriate measures.

An increasing focus on the importance of space for geographical regions and externalities of their populations proves the answer in a time of globalization where economies are transitioning towards new long-term equilibria, which are often subject to short- and medium-run processes at the regional level (Thissen & van Oort, 2010). According to the place-based perspective on the organization of space, variation between the individual components of a larger urban system facilitates the performance of the system as a whole, and not just the cities at the top of its hierarchy (OECD, 2011a; 2011b). Results generated from this study should strengthen the empirical basis on which place-based policies can be developed going forward, which should ease the shift to a more efficient policy development approach. In all this, future research using improved datasets, other geographical contexts or more detailed measurements could shed further light on our main findings and what they truly mean in an even broader context. So far, the results from our analysis disprove the widely-assumed usefulness of polycentricity, especially for larger urban areas, and suggest that a reliance on singular mega cities is not that disadvantageous after all.

APPENDIX

A1: Overview of the 168 TL2 regions included

Macro-region	Countries	Number of TL2 regions
North	Belgium	3 (NUTS1)
	Ireland	2 (NUTS2)
	The Netherlands	4 (NUTS1)
	Sweden	5 (NUTS2)
	United Kingdom	12 (NUTS1)
		Total: 26
Centre	France	22 (NUTS2)
	Germany	38 (NUTS2)
		Total: 60
South	Italy	20 (NUTS2)
	Greece	4 (NUTS1)
	Portugal	4 (NUTS2)
	Spain	16 (NUTS2)
		Total: 44
East	Austria	6 (NUTS2)
	Czech Republic	6 (NUTS2)
	Hungary	7 (NUTS2)
	Poland	15 (NUTS2)
	Slovakia	4 (NUTS2)
		Total: 38

A2: Correlation matrix of all variables included in the estimations

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) TFP (ln)	1.0000	0.3935	0.3855	0.0852	0.2599	-0.7301	0.4924	0.4451	0.0330	-0.1353	0.5458	-0.1180	-0.0074	-0.0459	-0.0506	0.2075	-0.1608
(2) Education (ln)		1.0000	0.2553	-0.2330	0.4143	-0.2978	0.3589	0.4333	-0.0903	-0.2578	0.3365	-0.0908	-0.0436	0.0089	-0.0914	-0.1331	-0.3542
(3) Hi-tech employment LQ (d)			1.0000	-0.2955	0.2260	-0.2784	0.5971	0.3078	0.1370	-0.2878	0.1722	-0.0596	-0.4219	-0.0594	-0.2073	0.2691	-0.3891
(4) Southern Europe (d)				1.0000	-0.2372	-0.3070	-0.4748	0.0590	-0.0553	0.0385	0.1576	0.0134	0.0816	-0.0186	0.0761	-0.1028	0.0560
(5) Northern Europe (d)					1.0000	-0.2294	0.0969	0.3108	0.1859	-0.0771	0.2610	0.0538	0.0668	0.2806	-0.0529	0.3913	-0.1246
(6) Eastern Europe (d)						1.0000	-0.2101	-0.1599	-0.1224	-0.0557	-0.3834	-0.1150	-0.0628	-0.0735	-0.1017	-0.2402	-0.0688
(7) Connectivity (ln)							1.0000	0.2445	0.0721	-0.2217	0.0806	-0.1426	-0.3481	-0.0168	-0.1564	0.1414	-0.2962
(8) Urban population size (ln)								1.0000	0.1849	-0.3598	0.6611	-0.1232	0.0508	-0.0795	-0.1165	0.2044	-0.3411
(9) Polycentricity (ln)									1.0000	0.1514	0.1790	0.3929	0.2381	-0.2498	0.1536	0.5486	0.2352
(10) Dispersion (ln)										1.0000	-0.1575	0.2617	0.6397	0.1107	0.7675	0.3220	0.7683
(11) Urban population size in 1850 (ln)											1.0000	0.0363	0.2518	-0.0620	-0.0842	0.3655	-0.2351
(12) Polycentricity in 1850 (ln)												1.0000	0.2435	0.1244	0.1426	0.6821	0.3480
(13) Land area in square kilometres (ln)													1.0000	0.0352	0.5409	0.4332	0.8230
(14) Size x Polycentricity														1.0000	0.0407	0.1769	0.0833
(15) Size x Dispersion															1.0000	0.2096	0.6188
(16) Size x Polycentricity (predicted values)																1.0000	0.4035
(17) Size x Dispersion (predicted values)																	1.0000

A3: First-stage regression results for the TSLS estimations

A3.1: Results for three endogenous variables (size, polycentricity and dispersion)

	Dependent (endogenous) variable		
	(1)	(2)	(3)
VARIABLES	Size	Polycentricity	Dispersion
Urban population size in 1850 (ln)	0.48***	0.10	-0.23***
	(0.06)	(0.07)	(0.06)
Polycentricity in 1850 (ln)	-0.07	0.38***	0.06
	(0.08)	(0.08)	(0.04)
Land area in square kilometres (ln)	0.11*	0.29***	0.62***
	(0.07)	(0.08)	(0.15)
Education (ln)	0.81***	-0.97***	-0.49***
	(0.22)	(0.31)	(0.15)
Hi-tech employment LQ (d)	0.47***	0.39*	0.07
	(0.15)	(0.21)	(0.10)
Southern Europe (d)	0.85***	0.13	-0.05
	(0.21)	(0.21)	(0.17)
Northern Europe (d)	0.48***	0.60***	-0.05
	(0.16)	(0.22)	(0.13)
Eastern Europe (d)	0.92***	0.12	-0.33*
	(0.21)	(0.22)	(0.18)
Connectivity (ln)	0.40**	0.52**	0.12
	(0.23)	(0.26)	(0.14)
Constant	5.63***	-1.09	-3.79**
	(1.07)	(1.25)	(1.57)
1st stage F-stat	29.58***	24.92***	6.75***
1st stage SW F-stat	54.00***	19.71***	24.15***
Observations	166	166	166
R-squared	0.68	0.69	0.67

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

A3.2: Results for four endogenous variables (size, polycentricity, dispersion and size x polycentricity)

	Dependent (endogenous) variable			
	(1)	(2)	(3)	(4)
VARIABLES	Size	Polycentricity	Dispersion	Size x Poly
Urban population size in 1850 (ln)	0.23	-0.08	-0.29*	-1.58***
	(0.19)	(0.16)	(0.17)	(0.30)
Polycentricity in 1850 (ln)	-0.87	-0.20	-0.13	-4.42***
	(0.57)	(0.57)	(0.52)	(1.00)
Land area in square kilometres (ln)	-0.56	-0.18	0.46	-3.84***
	(0.49)	(0.48)	(0.49)	(0.85)
Size x Polycentricity (predicted values)	0.17	0.12	0.04	0.97***
	(0.12)	(0.12)	(0.11)	(0.21)
Education (ln)	3.02*	0.60	0.02	12.06***
	(1.56)	(1.58)	(1.40)	(2.76)
Hi-tech employment LQ (d)	-0.43	-0.26	-0.14	-5.60***
	(0.66)	(0.68)	(0.60)	(1.16)
Southern Europe (d)	0.52	-0.10	-0.13	-1.71***
	(0.33)	(0.29)	(0.33)	(0.53)
Northern Europe (d)	-1.06	-0.51	-0.41	-7.33***
	(1.11)	(1.11)	(1.04)	(1.90)
Eastern Europe (d)	0.63**	-0.09	-0.40	-1.88***
	(0.30)	(0.24)	(0.33)	(0.47)
Connectivity (ln)	-0.59	-0.32	-0.16	-6.33***
	(0.88)	(0.81)	(0.82)	(1.51)
Constant	8.28***	0.80	-3.18	17.13***
	(2.32)	(2.08)	(2.71)	(3.79)
1st stage F-stat	28.59***	18.70***	5.27***	8.51***
1st stage SW F-stat	42.81***	15.39***	22.50***	30.35***
Observations	166	166	166	166
R-squared	0.68	0.69	0.67	0.67

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

A3.3: Results for four endogenous variables (size, polycentricity, dispersion and size x dispersion)

	Dependent (endogenous) variable			
	(1)	(2)	(3)	(4)
VARIABLES	Size	Polycentricity	Dispersion	Size x Disp
Urban population size in 1850 (ln)	-0.11	0.01	0.65	1.74***
	(0.47)	(0.39)	(0.78)	(0.48)
Polycentricity in 1850 (ln)	0.07	0.40***	-0.16	-0.48***
	(0.14)	(0.12)	(0.21)	(0.12)
Land area in square kilometres (ln)	1.58	0.52	-1.58	-4.28***
	(1.17)	(0.95)	(2.02)	(1.22)
Size x Dispersion (predicted values)	-0.18	-0.03	0.26	0.57***
	(0.14)	(0.11)	(0.23)	(0.15)
Education (ln)	-0.40)	-1.16	1.32	3.95***
	(0.99)	(0.81)	(1.57)	(1.03)
Hi-tech employment LQ (d)	0.59***	0.41*	-0.12	-0.28**
	(0.19)	(0.22)	(0.22)	(0.14)
Southern Europe (d)	0.72***	0.11	0.15	0.56***
	(0.22)	(0.23)	(0.14)	(0.17)
Northern Europe (d)	0.29	0.57**	0.25	0.55**
	(0.21)	(0.22)	(0.24)	(0.22)
Eastern Europe (d)	0.06	-0.01	0.95	2.56***
	(0.68)	(0.60)	(0.99)	(0.69)
Connectivity (ln)	0.86***	0.56*	-0.29	-0.80***
	(0.31)	(0.31)	(0.45)	(0.26)
Constant	-3.07	-2.43	9.19	23.92***
	(7.06)	(5.76)	(12.60)	(7.32)
1st stage F-stat	23.57***	18.77***	8.38***	6.19***
1st stage SW F-stat	49.01***	15.51***	7.58***	8.80***
Observations	166	166	166	166
R-squared	0.68	0.69	0.67	0.67

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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