Defining and measuring polycentric regions: the case of Tuscany

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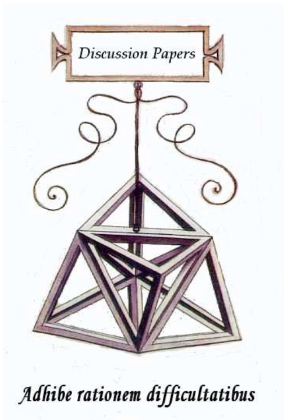

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Discussion Paper

n. 101

David Burgalassi

Defining and Measuring Polycentric Regions. The Case of Tuscany

Abstract

Polycentric development in regions has many dimensions, which involve several definitions and measures. This paper tackles the problem of defining and measuring polycentricity under an integrated and multi-dimensional perspective. Firstly, the policy relevance of polycentricity is analysed. Then, the paper identifies the definitions and measures of polycentricity by surveying the literature. It also provides a taxonomy among two main aspects involved in the definition of polycentricity: the morphological dimension and the functional dimension. Based on this background, an empirical analysis is carried out, by using data about population and commuting flows in the Tuscany Region (Italy). The results show that Tuscany can be viewed as a polycentric spatial structure, both considering rank-size distribution of cities and spatial interaction.

Classificazione JEL: O18, R11, R12.

Keywords: Polycentric Development, Spatial Structure, Rank-size Estimations, Spatial Interaction, Tuscany.

Contents

I. Introduction

This paper analyses the problem of identifying and measuring polycentricity in regions. Polycentric development and polycentric spatial structures in regions have become an important analytical concept, as well as a popular normative goal of spatial planning. European policies have recognized that polycentric configurations in regions can be intended as mean to achieve multiple goals, namely more *efficient*, *balanced* and *sustainable* patterns of spatial development (Commission of the European Union, 1999). However, the consolidated wisdom about the supposed advantages of polycentric regions appears to be at least questionable and unclear. We argue that this unclearness is due to a lack in the definition – and then the measurement – of polycentricity. So, a main goal of this paper is trying to answer the question "*what is a polycentric region?*" and to investigate the several dimensions involved in the definition of polycentricity, focusing in particular on two aspects, namely the *morphological* and the *functional* polycentricity.

What emerges from this theorical reflection is then applied to the analysis of polycentric development in Tuscany, an Italian NUTS 2 Region. Both literature and spatial planning policies (Regione Toscana, 2005) have recognized how Tuscany might be described as a polycentric region or, in other words, a "regional system" composed by some separate and distinct nodes (cities) that interact with each other to a significant extent. However, this statement seems to lack of empirical confirmation. So, this paper aims to investigate the several dimensions involved in the measurement of polycentricity in Tuscany, investigating if Tuscany can be effectively described as a polycentric urban system, considering both dimensions of polycentricity.

The paper is organized as follows. Section 2 describes the increasing importance of the concept of polycentric development, both for European policies and, more specifically, in Tuscany. Section 3 gives account of theoretical background and describes the methodology applied. Section 4 describes the findings of the empirical analysis. Finally, Section 5 gives the conclusions.

II. The economic relevance of polycentric development

This section deals with the notion of polycentric development, by showing its increasing relevance both for policy and academic debate. We describe that, although the notion of polycentric development seems to be quite consolidated, there are also several fuzzy and shaded issues that need further investigation. First, we briefly summarise the controversial effects of polycentricity on economic efficiency, regional disparities and environmental sustainability. Then, we focus on the debate about polycentricity in Tuscany.

II.A. The (European) policy debate

The issue of polycentric development has attracted strong interest particularly after the European Spatial Development Perspective (Commission of the European Union, 1999, From here onwards ESDP) and is now developing as one of the key-notions for spatial planning policies, as a way to achieve a *higher*, *more balanced* and *more sustainable development* of urban and regional areas. The importance of the concept of polycentric development has also been stressed in the academic debate, since many authors studied the emergence of polycentric spatial structures and their implications on the economies and the physical systems, see, e.g. Priemus (1994), Lambooy (1998), Kloosterman and Lambregts (2001), Davoudi (2003), Parr (2004), Meijers (2008). Two major research issues have attracted the debate on polycentric development. On the normative side, the debate has focused on the economic relevance of polycentric spatial structures, that is, on the potential advantages from polycentricity. On the positive side, research has been devoted to the definition of polycentricity and its main features. The first issue is dealt with in this section, the second one in section 3.

II.B. Polycentric development: a tool to achieve multiple goals?

Regional polycentric development is intended by policy – by EU policies in particular – as a mean to achieve multiple goals, namely more *efficient*, *balanced* and *sustainable* patterns of spatial development in regions. In particular, the ESDP states that "spatial development policies promote the sustainable development of the EU through a balanced spatial structure", by the development of a "balanced and polycentric urban system" in order to achieve a "balanced regional development" (Commission of the European Union, 1999, 20-21).

However, it is not clear why polycentric development should foster *competitiveness*, *cohesion* and *sustainability* in regions. This is a shared point in the literature (Davoudi, 2003; Kloosterman and Musterd, 2001; Meijers, 2008; Parr, 2004), as everybody claims for further research in the field.[1]

Polycentric development and efficiency The ESDP implicitly assumes that, switching from monocentric to polycentric configuration, regional systems would avoid the disadvantages caused by congestion and, at the same time, continue to get the benefits of agglomeration, provided that the centres belonging to regions were able to interact to each other. The result would be an increase in efficiency. In fact, since agglomeration is crucial in fostering diversity of production and lowering transaction and transportation costs, the connections and interdependencies characterising polycentric regions may lead to the same benefits arising within metropolitan agglomerations. [2]

However, this appears to be, at least, a remarkable proposition. In fact, economies of agglomeration seem to arise only where a "critical mass" is reached (Glaeser et al., 1992). So, it is questionable if

[1] See, in particular, Davoudi (2003) who explains how this concept is successful in the political debates, while it still remains fuzzy in the research agenda.

[2] As noticed by Johansson and Lambregts, "networks among economic actors dispersed over space may act as substitute for agglomerations of actors at a single point, providing some or all of the utility gains and productivity increases derived from agglomeration" (Johansson and Lambregts, 2004, 166).

this critical mass could be reached by regions based on medium and small sized cities, like Tuscany. Then, polycentric regions do not necessarily present the systems of relationships necessary to provide externalities: in other words, "polycentric" system does not necessarily mean "networked" system (Meijers, 2008).

Hence, it is still questionable if polycentric spatial structures may allow the emergence of agglomerative economies and the spread of these external benefits by the network relationships between cities.

Polycentricity and regional disparities According to the ESDP polycentric development can contribute to territorial cohesion and to the reduction of regional disparities, since regional spillovers are supposed to spread evenly across countries.[3]

However, the few studies that attempted to study this relationship have unclonclusive results. At the moment there is a lack of empirical confirmation showing that polycentric regions are characterised by less disparities and that polycentricity enhances the efficiency of pheripheral regions. Moreover, the successful case-studies are mainly located in central regions, like those in the North-West of Europe (Davoudi, 2003). Meijers and Sandberg (2006) show – by using data on regional disparities – how monocentric regions might be characterised by less disparities, as compared to polycentric areas. Their conclusion is that the "assumed positive relationship between a polycentric urban system and limited regional disparities lacks both a strong theoretical underpinning and empirical justification" (Meijers and Sandberg, 2006, 1).

Polycentric development and environmental sustainability Environmental sustainability is one of the main goals in the European Planning framework and polycentric development is intended as a way to achieve a more sustainable spatial configuration.

[3] "A policy is now required to offer a new perspective for the peripheral areas through a more polycentric arrangement of the EU territory" (Commission of the European Union, 1999, 20).

The main argument is that polycentric configurations might avoid urban *sprawl*, which is the spreading of cities over their surroundings – mainly rural or natural areas. In fact, polycentric regions are poles apart both from monocentric regions and scattered/sprawled regions (see figure 1). First, polycentric regions should be constituted by *compact* cities, while urban sprawl is characterised by unplanned settlements that spread across territory. Second, centres belonging to polycentric regions should be characterised by physical separation, called *open space* (i.e. natural or agricultural land) in between them.

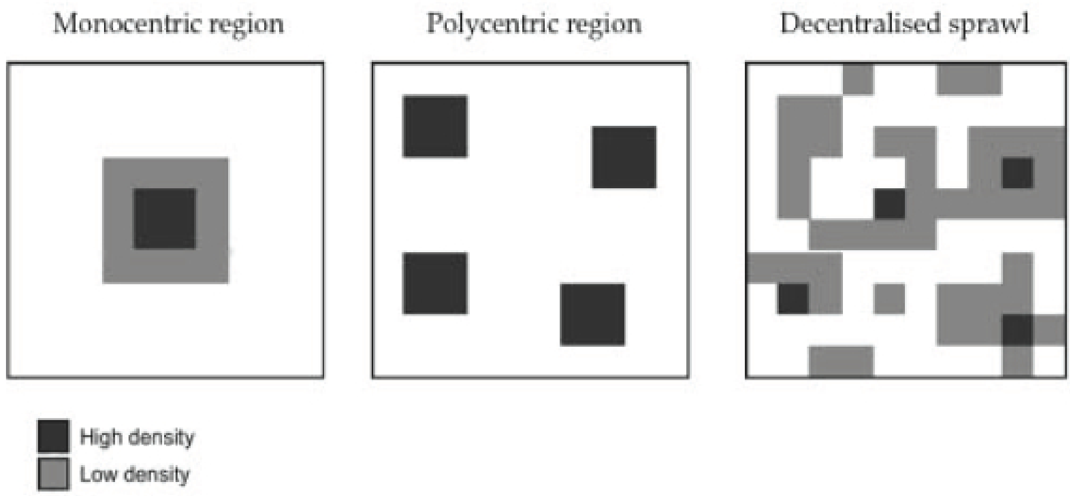


Figure 1: Monocentric, polycentric and scattered spatial structures.

The advantages of compact cities, as compared to sprawled regions, have been deeply studied, for instance by Camagni et al. (2002). The former would allow a better land use and less urban dispersion, maintaining the open space in between cities. Moreover, polycentric configurations might contribute to the reduction of private transportation, which is one of the main consequences of sprawled cities, with efficiency gains in terms of energy use, while also reducing the congestion costs arising in monocentric configurations.

However, also the opposite could happen: in presence of high levels of interaction among the centres, polycentric urban configurations might stimulate cross-flows made by private transport (car), if regional public transport is not sufficiently developed (Hall, 1993, 888).

II.C. Polycentric development in Tuscany

Both literature and policy documents have described Tuscany as a polycentric spatial structure. In fact, the region has been historically characterised by the presence of small and medium-sized entreprises, which are spatially organised in the form of the so-called *industrial districts* — i.e. the classic marshallian clusters — economically specialised and spatially spread across the region.

The spatial configuration of industrial districts has allowed to introduce the notion of "Tuscanies of Tuscany", which has been first proposed in 1975 by a study who identified four main types of functional local systems (IRPET, 1975) [4]. The Marshallian districts were part of one of those systems, called the "urbanized countryside" (*campagna urbanizzata)*: this notion described the areas, mainly neighboring urban agglomerations, in which manufacturing activity clustered. This form of spatial development was characterised by a distribution of productive activities across space who tended to minimize transport costs of workers, who still keep their residential activity in the villages of origin: as a result, a network of productive and residential clusters arised in the region.[5]

Subsequent research moved along those lines and further developed the idea that Tuscany can be read as a polycentric region (e.g. (Cavalieri, 1999, 193)).[6]

More recently, the polycentric spatial structure of Tuscany has been taken explicitly into account, from a normative point of view,

[4]This work, which analysed the economic development of the region from the Fifties to the half Seventies, focused on the development of manufacturing sector, leaded from external demand and exports.

[5]"Questo porta ad una distribuzione delle fabbriche nel territorio tale da minimizzare tendenzialmente i costi di spostamento di una mano dopera che mantiene, in misura sensibile, gli insediamenti abitativi originari o si sposta, comunque, su centri minori o intermedi ripartiti abbastanza uniformemente sul territorio . Si forma cos una specie di reticolo di insediamenti produttivi ed abitativi che la base della campagna urbanizzata" (IRPET, 1975, 35)

[6]"Strettamente collegata al paesaggio rurale, spesso in esso inserita, la forma di insediamento basata sulla distribuzione della popolazione in piccoli centri, se non i case sparse. la policentricit della toscana fonte di vitalit del tessuto".

by the main document of regional spatial planning: *Piano di Intervento Territoriale 2005-2010* (Regione Toscana, 2005). The Plan considered polycentricity as a key-issue, taking into account both the structure of cities and their functional relationships. Here, the concept of polycentricity is taken into account both a positive and a normative point of view. The former appear in the notion of "polycentric system of cities" and urban-rural relationships, while the latter states polycentricity as one of the main goals of regional spatial planning, which should should integrate and qualify Tuscany as a "regional polycentric city" (Regione Toscana, 2005, 44).

The present study aims at investigating polycentricity in Tuscany by focusing on the structure and functions of its centres, differently from the usual perspective that highlights polycentricity by studying the economic specialisation in clusters.

III. Defining polycentric regions

This section describes the main features characterising polycentric regions, by focusing on two aspects: the size and distribution of cities in polycentric regions (*morphological dimension*) and their interrelationships (*functional dimension*).

III.A. Morphological and functional dimensions

As pointed out in previous section, polycentric regional structures and their economic development have been subject to increasing interest and research. However, as emphatised before, the economic role of polycentric development in regions is still quite fuzzy. This unclearness begins from the definition of polycentricity and polycentric development. In fact, literature provides several definitions of polycentric region, in respect to the aspects taken into consideration. The diversity of definition derives from the fact that polycentricity and polycentric development in regions are *complex* concepts, involving multiple dimensions (morphological, economic, institutional, . . .) and various spatial scales.

From an economic perspective, the spatial structures have been investigated as strictly related to two forces that determine the localisation of economic activities: *agglomeration* and *dispersion*. Agglomeration is one of the key-stones in urban and regional economic analysis: it has been deeply investigated by economic theory, starting from Marshall (1890), which highlighted the crucial importance of "external economies of scale" referring to various types of economic advantages arising in cities [7]. Then, cumulative causation processes determine higher growth and consequently more incentive to concentration of economic activities in cities. In the meantime, also centrifugal forces – like transport and congestion costs – can be relevant, leading to the dispersion of economic activity over space. The combined effects of agglomerative and dispersive forces contribute to model the spatial structure of cities and regions. As consequence, spatial configurations are in between two extremes, total concentration of economic activity in one centre and uniform distribution over space.

It worth to remark that the notion of polycentricity has been applied to a variety of spatial scales, ranging from the intra-urban to the international levels [8]. Focusing on the regional level, the next step is to provide a description of the main features of polycentric regions, both from the *morphological* and the *functional* approach.

Morphological dimension The main aspects involved in the morphological dimension are the following:

1. clustering of separate centres, with lower and upper limits on centre separation;

2. size and spacing of centres;

[7] See, e.g., Anas et al. (1998) or Rosenthal and Strange (2004).

[8] The earliest studies on polycentricity refer to the intra-urban level - starting from Alonso (1964), and later developed, for instance, by Gordon et al. (1986) and Anas et al. (1998) – treating mainly the phenomenon of clustering of economic activities in *sub-centers* within urban areas.Anas et al. (1998), in particular, notes that economic activity does not expand uniformly over space, but some clusters arise: these spots are the sub-centers of economic activity in cities, leading to a polycentric configuration of the urban structure.

3. size - distribution of centres.

Point 1) means that cities belonging to a polycentric region are relatively close, but physically separate, with *open space* (i.e. rural or natural landscape) in between them. In general the distance between two centres i and j belonging to the same region should be in the range

$$d_{ij(min)} < d_{ij} < d_{ij(max)} \tag{1}$$

Where $d_{ij(min)}$ is the lower limit and $d_{ij(max)}$ the upper limit on centre separation. Both parameters can be expressed by euclidean or time distance. The value of $d_{ij(min)}$ represents the open space between cities, thus $d_{ij} > 0$ allows to distinguish polycentric regions from regions where coalesced/sprawled cities or conurbations prevail. The upper bound $d_{ij(max)}$ is a defined threshold that allow to circumscribe the region: it might be, for instance, the distance covered by a car trip of one hour (Green, 2007, 2087). The one-hour travel is a threshold used also to define *Daily Urban Systems*, which are the areas around cities where daily commuting occurs.[9]

Point 2) means that the spacing of cities across the region should be balanced: cities in an ideal polycentric region should have the same (physical or time) distance from each other.

Finally, the size-distribution (point 3) refers to the physical hierarchies in regions. According to this aspect, regions can be distinguished in *mono-nuclear* an *poly-nuclear*. The former are characterized by a strongly hierarchical structure, with one dominant city surrounded by peripheral/dependant cities, while the latter are characterized by cities equally sized.

Functional dimension The functional dimension involves at least two aspects: 1) the economic specialisation of centres and 2) the

[9] Alternatively, $d_{ij(max)}$ could be computed as

$$d_{ij(max)} = \bar{D} + \sigma_T \tag{2}$$

Where $\bar{D}$ is the average distance between cities, and σ_T is the standard deviation of all distances d_{ij} between cities belonging to the region Green (2007).

interaction among them.

Specialization of centers refers to the structure of economic activities in cities belonging to the regional system. According to some authors a system is polycentric when its economic structure is characterized by specialization across urban areas, leading to economic complementarities between cities (Kloosterman and Lambregts, 2001). A polycentric region is a system, included in the wider (national or international) system of regions. The economic competition among cities and regions leads to the specialization and the specialization promotes complementarities. As a result, cities become interdependent[10]. So, polycentric regions appear to be the ideal ground for the arise of *economies of variety*, like those illustrated by Jacobs (Glaeser et al., 1992) at the regional level (with positive effects due to the variety of production), while the urban scale would benefit from their specialisation and spillovers (Marshall-Arrow-Romer externalities within industries located in the same city [11]). As a consequence, clustering and specialisation of economic activities in centres belonging to a region can be used as indicators of the degree of polycentricity of its regional structure (Kloosterman and Lambregts, 2001).

In Europe, the Netherlands constitutes one of the most famous examples of functional specialisation of cities in polycentric regions. These aspects have been widely studied (Kloosterman and Lambregts, 2001; Meijers, 2007; Priemus, 1994) and made the Netherlands as an archetypal polycentric structure.

The other functional aspect is the interaction among centres. Cities are physically interconnected by infrastructures and by flows (e.g. flows of commuters, trade or information): these interrelationships would be characterized by higher intensity in polycentric regions, as compared to monocentric, since "*in a polycentric urban system the small and medium-sized towns and their inter-*

[10] "Functional specialisation is an important dimension of polycentricity, since it is these functions that make cities different from each other and produce the flows necessary for economic and political integration" (Nordregio, 2004, 50).

[11] see Rosenthal and Strange (2004).

dependencies form important hubs and links" (Commission of the European Union, 1999, 24). Moreover, flows in polycentric regions should be characterised by lower hierarchical restrictions: the result should be a relative "symmetry" of flows in polycentric regions – i.e. there are no dominant centre attracting flows from all the others (Kloosterman and Lambregts, 2001) – and mutual interdependencies between the centres.

Taking into account the interaction, regions are in between two extremes: mono-oriented regions, characterised by relations oriented towards one (dominant) centre, and multi-directional regions, characterised by relations with no obvious orientation.

A summary As seen above, the two main groups of aspects that one can identify are the "morphological" dimension and the "functional dimension". In the literature, the former has been investigated mainly by analysing the size distribution and the spacing of cities (IGEAT, 2007; Meijers, 2008; Nordregio, 2004), while the latter by taking into account the specialisation of centres (Kloosterman and Lambregts, 2001; Lambooy, 1998) and their mutual interdependencies (de Goei et al., 2008; Limtanakool et al., 2007; Nordregio, 2004).

In this work, both dimensions – morphological and functional – are considered. Specialisation hasnot explicitly been taken into account, but we focus on interaction. The reason is that specialisation is widely treated by the literature[12]. Moreover, *specialisation* and *interaction* are extremely linked to each other. In fact, one might expect that the more the cities belonging to a region are specialised, the more would be their mutual interdependencies (Parr, 2004). The latter might be made easier also by the development in transport and information technologies (Hall, 1993). As a consequence, integration between centres might easily arise in polycentric regions.

[12] See, for instance, Kloosterman and Lambregts (2001), Meijers (2007), Priemus (1994) or Lambooy (1998).

III.B. Measuring polycentricity

Once identified and classified the several dimensions involved in the definition of polycentricity, the question is *how to measure* them.

III.B.i. Measuring morphological polycentricity: Rank-Size distribution of cities

As pointed out above, size–distribution of centres is one of the most prominent aspects of the organisation of economic activity over space. One may investigate this characteristic in order to define the degree of polycentricity in regions. In this field, a wide range of the literature has shown some regularities in the size-distribution of population, as result of the mechanisms that lead the growth of cities. These regularities hold at several spatial scales. One of the most popular empirical evidence is the Zipf's Law for cities, according to which the distribution of city-size can be approximated by a power law distribution (Gabaix, 1999; Gabaix and Ioannides, 2004).[13]

In other words, the probability to find a city having size greater than S is inversely proportional to S. The form is:

$$P(Size > S) = \frac{a}{S^{\beta}} \tag{3}$$

where α and β are parameters. By ranking the sizes of the N cities:

$$S_1 \geq S_2 \geq \ldots \geq S_n \tag{4}$$

Considering the empirical distribution, the frequency follows the distribution:

$$P(Size > S_R) = \frac{R}{n} \tag{5}$$

where R is the rank position. So we can equalize equations 3 and 5 and operate on the right sides:

[13] This empirical regularity was first studied by the linguist K. Zipf, in order to study the frequency of use of words in English texts. Zipf's law states that the size of the r'th largest occurrence of the event is inversely proportional to it's rank.

$$\frac{a}{S^{\beta}} = \frac{R}{N} \Rightarrow an = RS^{\beta} \Rightarrow R = \frac{aN}{S^{\beta}} \qquad (6)$$

The Rank-Size rule is an approximation used in order to visualise Zipf's Law in a log-linear form [14]. Zipf's law has been mainly studied by taking into account population as index of city size. However, also other indicators have been applied, like employment (Anderson and Bogart, 2001). The measurement is done by ranking the cities according to their population (from the biggest to the smallest) and then by estimating the equation obtained by taking the logarithms of the last term of equation 6 (expressing aN as a constant α):

$$\ln(Rank) = \alpha + \beta \ln(Population) \qquad (7)$$

where the coefficient β is by construction negative. The case known as Rank-Size rule holds if the the value of β is -1 (Gabaix and Ioannides, 2004, 6): this means that the rank-size distribution is log-linear. In other words, if the rule holds, the largest city of a region is twice as large as the second, three times the size of the third, etc.[15] Actually, β is close to -1 in many regions and states, like in the USA (taking into account data on metropolitan areas), as shown by Gabaix and Ioannides (2004)[16] and other countries. However, some other studies refute the prediction of Zipf's law.

Rank-Size estimations can be used as a tool to measure polycentricity; the higher the absolute value of β, the more polycentric the region. However, there are some measurement issues. An important one is related to the impact of small cities on the estimation. Since regions are generally characterised by many small settlements and few bigger cities, the former can bias the estimation involving low βs (i.e. low polycentricity). So, it would be better to exclude the smallest settlements from the estimation. There are several techniques to do so. One considers a fix number of cities (e.g. the biggest 50 centres), or alternatively a fixed size threshold (e.g. 50 000

[14] See for instance, Gabaix and Ioannides (2004) for the economic explanations of Zipf's Law.

[15] Of course α must be set equal to $\ln(Population)$ of the largest city, in order to have $Rank = 1$.

[16] Gabaix and Krugman obtained both a slope of -1.005, with st. dev. 0.010.

inhabitants, or 20 000 in smaller regions). It would be also possible to take into account a size "*above which the sample accounts for some given proportion of a country population*" (Meijers, 2008, 1320). It is important to remark that the issue of thresholds is related with the functional form used: by using OLS one might estimate with high precision the distribution of biggest cities – that generally are log-linearly distributed – while the estimation would be less accurate by taking into account the entire sample.

Another issue impacting the results is the definition of city applied. It has been established that, by taking into account the administrative definition of cities, the estimated values of β are higher, as compared to more functional definitions of city, like urban agglomerations, functional urban areas or, in Italy, Local Labour Systems. So, the definition of city applied appears to be crucial.

The use of rank-size estimation appears to be a "*clear, theoretically founded definition of polycentricity*" (Meijers, 2008, 1318). In particular, rank-size regressions are a more informative tool, as compared to other measures of dispersion, like the standard deviation of the population in cities. Moreover, by comparing data over time, it is possible to get information about the evolution of urban systems: increasing values of β would show a trend towards polycentricity in the region.

However, this method presents some drawbacks. A first point that needs attention regards the technique used to estimate the values, as the ordinary least squares (OLS) estimation is biased and inefficient in small samples: in particular, the value of β is underestimated (Gabaix and Ioannides, 2004, 7-8). This is why other methods have been proposed, like the Hill's estimator.

Finally, even if this analysis provides a synthetic outline of the degree of polycentricity in regions, it does not capture the many other aspects of the phenomenon, since it focuses on the size-distribution of centres. First, it does not consider the spacing of centres and the limits on centre separation (especially the lower limit): so, for instance, a value of β increasing over time could mean a transition towards polycentric structure, but it could also imply a dynamic of sprawl and coalescence between cities, with severely different implications. Last, by using only this technique it is not possible to capture the specialisation and the interaction among centres.

So, it appears reasonable that rank-size estimations are not sufficient to describe the level of polycentricity in regions. This is why other measures have been proposed, like those taking into account "functional" polycentricity.

III.B.ii. Measuring functional polycentricity

As pointed out before, "functional polycentricity" refers both to specialisation of centres and their interconnections, two aspects that are closely linked to each other. This dimension is described by conceptualising the spatial level under analysis as a system composed of *nodes* and their *links*.

Several indicators can be utilised to analyse the interdependencies between centres: these refer to *flow* data. The most frequently used measures consider the travel-to-work intensity between cities, where "a situation with intense commuter flows in both directions would be a sign of integration and of polycentricity" (Nordregio, 2004, 48), but also other types of flows can be studied.[17]

There are many reasons to use data on commuting. In fact, commuting – i.e. house-to-work daily travelling – represents one of the main features of interaction between close centres, since it is relatively easy to measure, while for other measures of spatial interaction it is very difficult to get the data (e.g. information flows). Even if it is true that commuting is only one of the possible interrelations between cities, it can be considered a good proxy for the relational densities in spatial systems (Calafati, 2005). Moreover, the use of commuting flows allows to locate the *loci* of residential activities and those of economic activities and to distinguish between them, by analysing the directions and intensity of movements among cities.

[17]Camagni and Salone (1993), for instance, propose to utilise the total amount of communications and information flows going out of and into each centre.

Commuting patterns are strictly linked with *density*. Higher density is associated with lower commuting towards other centres (the flows are concentrated in the city), while less urban density is mainly associated with more commuting, because of the dispersion of residential activity (Anas et al., 1998). However, the results in the literature are contrasting (Sohn, 2005).

Indexes of spatial interaction By using commuting data, some indicators of intensity of the interrelationships between cities can be computed and used to interpret the degree of polycentrism in regions. Several techniques can be used to deal with flow data – commuting flows in particular. Network analysis theories have developed some indicators, starting from the concept of *nodes* and *links* between nodes, within a *spatial system*. The insights of the network theory can be applied to the study of spatial structure.

The indicators of spatial interaction can refer to the entire system (region), the nodes (cities) or the links between nodes (flows). In the first case, the level of integration and intensity of the interrelationships is measured via aggregate indicators. However, also the cities can be used as unit of analysis, as they are the nodes where flows origin and destine. Last, one might consider the links between the cities: here the units of analysis are represented by the flows between centres.

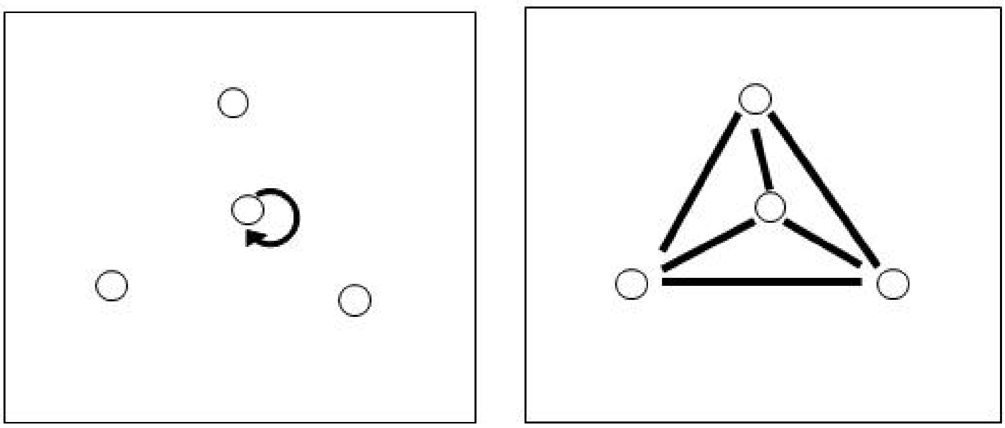
A useful set of indicators is provided by the studies of Limtanakool et al. (2007, 2009). They proposed indexes referring both to the entire system and the single centres and the links– in order to describe the “S-dimensions”: structure, strength and symmetry of spatial systems.

Structure The Entropy Index (EI) is a synthetic indicator of the structure in the entire regional system. It has been defined as follows by Limtanakool et al. (2009):

$$EI = -\sum_{i=1}^{L} \frac{(Z_i)ln(Z_i)}{ln(L)} \tag{8}$$

where Z_i is the ratio between the trips involving the node (city) i and the total number of trips of the entire region and L is the total number of cities. For each city, these trips can be either *to* other centres, *from* other centres or *intra-city*. Limtanakool et al. (2009), for instance, consider the trips *from* other cities.[18]

Ranging from 0 to 1, it measures how the total interaction is distributed between cities: hypothetically, a value 0 would mean that all flows are concentrated on a unique city (Figure 2 a), while a value 1 reflects a fully polycentric system (Limtanakool et al., 2009, 183) in which all centres are involved in the interaction, with equal intensity (Figure 2 b).



(a) *EI = 0.* (b) *EI = 1.*

Figure 2: Entropy Index.

According to Limtanakool et al. (2009), the total amount of flows involving each city (node) has to be taken into account. However, one might also consider separately *out-commuting* and *in-commuting* flows and compute two distinct Entropy Indexes, which we call Entropy Index for in-commuting and Entropy Index for out-commuting.

[18]By definition, for Z_i= 0 holds that $(Z_i)ln(Z_i) = 0$.

The former considers only the *exits* from each centre, while the latter takes into account the *entries*.[19]

The comparison between these twoindexes – with reference to the same regional system – would allow to take into account the separation between residential and economic activities. High values for the EI referring to in-commuting would mean a polycentric structure in terms of job markets, while high values of out-commuting might reflect a polycentric in the residential structure. In general one might expect the EI for in-commuting lower respect the EI for out-commuting, since the residential activity is more spread than the spatial job markets and more the region would be polycentric in terms of distribution of the economic activity. Thus, the higher the difference between the indexes, the higher the separation between *residential* and *job spaces*. This aspect is strictly linked with the *symmetry* (see below): ideally, a perfect polycentric structure would be described by symmetry and same intensity of flows among all cities in regions.

The entropy can also be computed for each node, by a similar formula, obtaining the Entropy Index at node level (Limtanakool et al., 2009):

$$EI_i = -\sum_{j=1}^{J} \frac{(x_j)ln(x_j)}{ln(J-1)} \tag{9}$$

where, x_j is the proportion of flows from node j to node i in relation to total flows from node j. J is the total number of destinations from i. The Entropy index at node level describes how much a centre is involved in the total amount of flows: in a fully polycentric system the value would be 1 (as all the flows respect to a node have the same value) for every node.

Strength This dimension concerns the intensity of interaction between nodes. By taking into account this aspect, one might see,

[19] Obviously, the total values of in-commuting and out-commuting for the entire region should be equal, if one excludes the flows involving other regions.

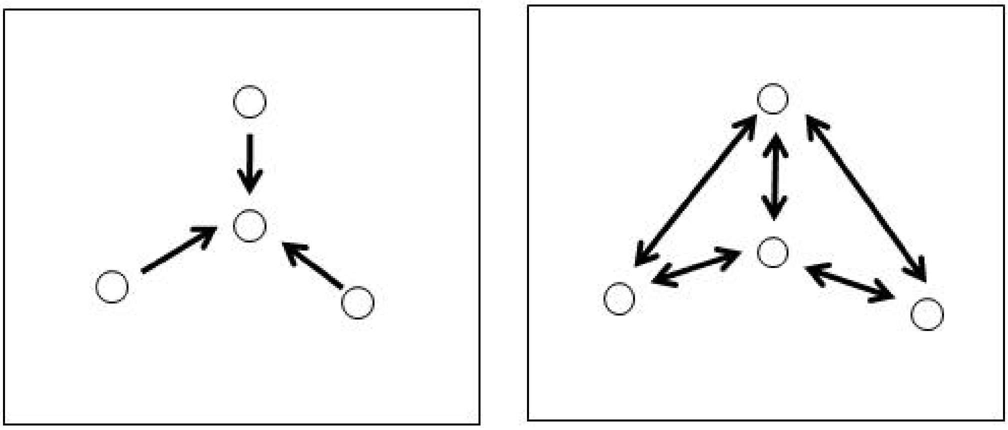
in a region, what are the centres involving the higher intensity of interaction, measured in terms of attraction of flows from other cities.

A first indicatorof strength of a city i is the ratio of in-commuting respect to population or employment in the city, in order to see which are the main centres attracting workers.

Another indicator, which was proposed by Limtanakool et al. (2009), is the Dominance Index (DI_i). It is defined at the node level and it takes into account the ratio of in-commuting to a city respect to the total commuting of a region:

$$DI_i = \frac{I_i}{(\sum_{j=1}^{J} I_j/J)} \tag{10}$$

where I_i is the sum of the trips inwards i from all other locations, and I_j the inward flows to each other location j, while J is the total number of cities. I_j is normalised by the average value of flows inward cities belonging to the spatial system ($\sum_{j=1}^{J} I_j/J$). The intuition is straightforward: the DI_i aims to measure to what extent a city attracts flows from the other centres, respect to the average degree of "attractiveness" of the region ($\sum_{j=1}^{J} I_j/J$). In other words, it measures whether a node dominates the network or not. DI_i ranges from 0 to ∞. It measures the dominance of a node relative to the total network: hypothetically, an infinite value would indicate that every interaction in the network is associated to the node (so it dominates the whole network), while a zero value would indicate that the node is not involved at all in the network. The maximum degree of polycentricity would occur if $DI_i = 1$ for every centre: it would mean that every city attracts the same intensity of flows. It is interesting to know how the DI is distributed. A high standard deviation of the index indicates that higher values are associated with one or few cities attracting flows from the others (see Figure 3 a), while a more even distribution of the index would characterise polycentric regions, since the in-commuting flow to each city are similar to each other (see Figure 3 b). So, this indicator can be useful to rank the cities and to see if the system presents strong or less hierarchies: the latter should happen in polycentric systems.



(a) *High dominance of the central node.* (b) *Equal dominance for all nodes .*

Figure 3: Dominance Index.

The strenght can be analysed also taking into account the links, instead of the nodes. The strength of one link between two nodes can be computed by the Relative Strenght Index (RSI_{ij}), which is defined at the link level, as follows Limtanakool et al. (2009):

$$RSI_{ij} = \frac{T_{ij}}{\sum_{i=1}^{I} \sum_{j=1}^{J} T_{ij}} * 100 \qquad (11)$$

where T_{ij} represents the flow from node i to node j. The RSI has values between 0 and 1. A value 1 for one link and 0 for all the others would mean that all flows are concentrated on the link between i and j, while if the values of RSI_{ij} are equal for all link, there is no hierarchical structure.

Symmetry This aspect refers to the direction of flows among cities in a spatial system, which contributes to explain their hierarchies of centres inside a region.

From this point of view, an indicator can be represented by the balance between out-commuting and in-commuting (or net flows), which gives the information about the degree of “attractiveness” of the city:

$$B_i = I_i - O_i \qquad (12)$$

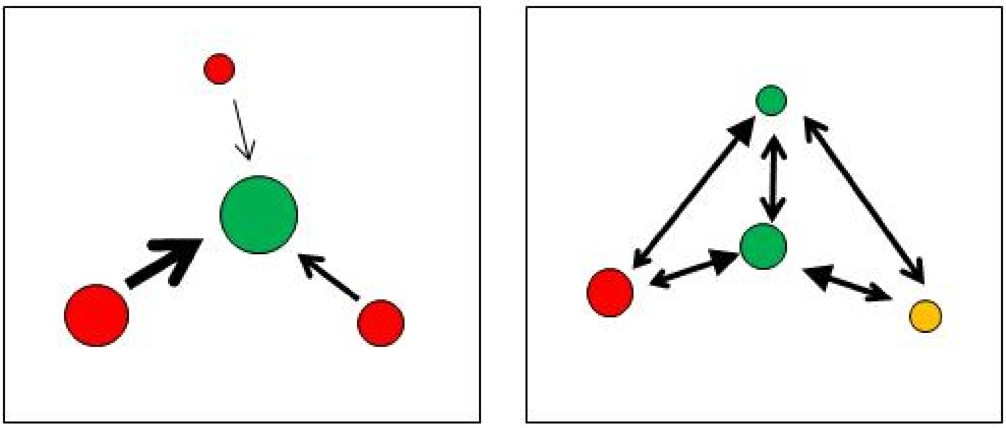
where I_i and O_i represent the total amount of in-commuting (flows "to" city i) and out-commuting (flows "from" city i) respectively.

The Node Symmetry (NSI_i) is a development of the indicator above mentioned. It is defined as follows (Limtanakool et al., 2009):

$$NSI_i = \frac{I_i - O_i}{I_i + O_i} \tag{13}$$

where O_i is the number of journeys originating from node i [20]. A value of 0 would mean that the node is fully symmetrical in terms of net flows. *A network does not have a hierarchical structure when every node in the network has NSI_{ij}=0*" (Limtanakool et al., 2009, 184). If one city has only out-commuting ($I_i = 0$), this means $NSI_i = -1$, while $NSI_i = 1$ holds for centres who have only in-commuting ($0_i = 0$). In Figure 4 (a) the central node has $NSI_i = 1$, while NSI_i would be -1 for all other nodes.

Average value and standard deviation of NSI_i for centres belonging to a region would give insights about the direction of flows between cities.



(a) *Monocentric configuration.* (b) *Polycentric configuration .*

Figure 4: Node-Symmetry Index.

Similarly, the symmetry can also be defined for each link (flow), via a Link Symmetry Index (LSI_{ij}):

[20]Node-Symmetry Index is comparable to the Grubel-Lloyd index, which is the measure of the intra-industry trade suggested by Grubel and Lloyd (1975).

$$LSI_{ij} = \frac{f_{ij} - f_{ji}}{f_{ij} + f_{ji}} \tag{14}$$

where f_{ij} is the amount of flows on the link from node i to node j and f_{ij} is the amount of flows from j to i. This index ranges from -1 to 1. A value $LSI_{ij} = 0$ indicates a perfect symmetry in flows between nodes i and j, while $LSI_{ij} = 1$ would indicate that all the flows on the link are from i to j. With reference to Figure 4 (a), all links have $LSI_{ij} = 1$, where j is the central city.

IV. Measuring polycentricity in Tuscany

IV.A. Morphological Polycentricity: Rank-Size Estimations

IV.A.i. Data and their treatment

Data used in this section were collected from the results of the General Census of Population [21] referring to the population in the municipalities of Tuscany in years 1981, 1991 and 2001. Last available data, referring to year 2008, were also collected from Italian Statistical Bureau website [22].

Cities were ranked according to their population and density and the following specification was estimated:

$$\ln(Rank) = \alpha - \beta \ln(Population) + \epsilon \tag{15}$$

where the coefficient β gives the value of structural polycentricity for each year. Higher β means higher degree of polycentricity. [23]

As described in previous section, the thresholds applied (i.e. the number of cities taken into account) are crucial for the value of β. So, in order to test the robustness of the procedure, the analysis was conducted by considering several thresholds. In particular equation

[21] Italian Statistical Bureau, `http://www.istat.it`.

[22] `http://demo.istat.it/`

[23] For the convenience of the reader, it was estimated $-\beta$, instead of β, used in equation 6, since β is negative by construction.

15 was iterated for cities ranking from the biggest 10 to the biggest 150. [24].

The previous section highlighted the importance of the choice of the units of analysis. Another approach on rank-size regression is to consider urban agglomerations, instead of municipalities. The former are clusters of neighboring municipalities around a central city (*centroid*). Here *Local Labour Systems* (LLS) were used as proxies for urban agglomerations. Italian Statistical Bureau defines LLS from the results of every Census of Population, by taking into account the relationships described by commuting flows among neighboring municipalities in the year of the Census: as a consequence, both the number of LLS and their borders change every 10 years (Calafati, 2005). In ordet to keep fixed the boundaries (and due to the fact that there are not data for the borders previous of 1991), we considered the 57 LLS defined at year 2001 as proxy for the urban agglomerations. The same procedure was applied also to other Italian NUTS2 regions, in order to see the relative degree of polycentricity of Tuscany, as compared to other regions.

IV.A.ii. Findings

Population The results of rank-size estimations are presented in Figure 1. Three main stylised facts worth to be higlighted:

1. The value of β is always above 1. This can be considered as an indicator of considerable level of polycentricity.

2. The level of morphological polycentricity is constantly increasing over time (see Figure 5). From 1971 to 2001 population declined in the biggest cities, while smaller centres increased. By considering all estimations for each year, in 1971 the average value of β was 1.14 (with a mininum of 1.12 and maximum of 1.24), while it was 1.24 in 2001 (see Table 1).

3. The level of morphological polycentricity is higher for main cities, while decreases if smaller settlements are taken into account.

[24] The city ranked as 150 counted 4 833 inhabitants, in 2001.

This is shown with the help of Figure 5: β monotonically decreases until we take into account around 40-50 observations.

Year	Mean	Min	Max
1971	1.143	1.120	1.244
1981	1.161	1.115	1.276
1991	1.188	1.136	1.316
2001	1.228	1.168	1.363
2008	1.243	1.181	1.367

Table 1: Values of β for each year, n ranging from 10 to 150.

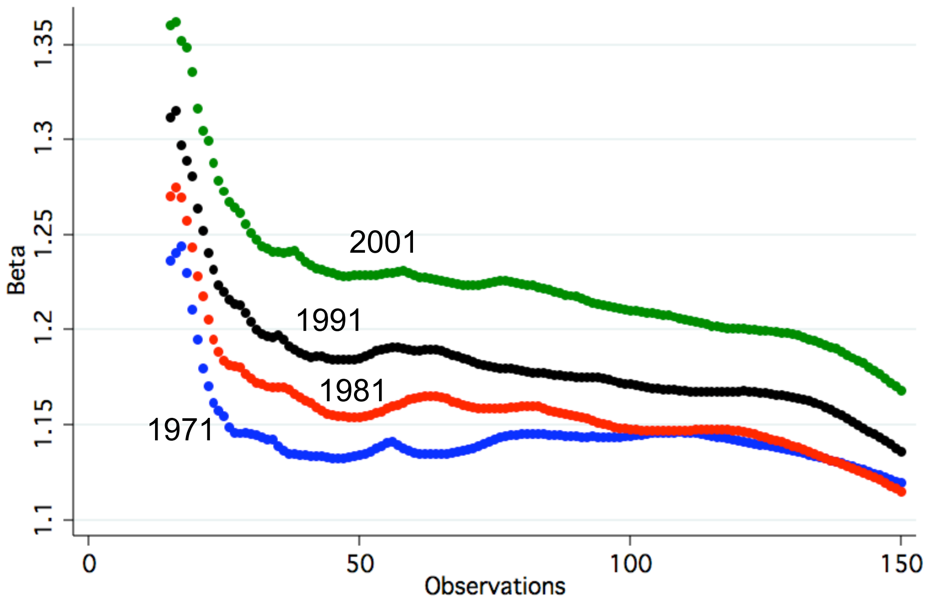


Figure 5: Values of β, Tuscany, years 1971, 1981, 1991, 2001.

Estimation on urban agglomerations Figure 6 shows the results of the estimations: the level of polycentricity slightly changed over time, but to a less extent, as compared with results on municipalities: moreover, it did not change on average (see Table 2). The level of polycentricity increases by considering bigger agglomerations (till the 20th), while it seems to decrease by taking into account the whole sample, especially for number of observations ranging from 38 to 55. So, it is possible to infer that the increase of β found by taking into account municipalities is mainly due to a relative increase in major urban agglomerations. In other words, people tended to redistribute to main centres to other neighboring cities, while population declined in marginal agglomerations.

This phenomenon can be visualised by using cluster and outlier analysis, which is a tool from spatial statistics. Taking into account the population growth from 1971 to 2001, Local Moran's I statistic were computed. This statistics is useful to see how values spatially cluster. Figure 7 provides the results. The map illustrates the negative value of Florence and the positive values of the municipalities around it. Another interesting case is the value of Pisa, and again the negative values of its neighbouring municipalities.

Year	Mean	Min	Max
1971	1,048	0,660	1,356
1981	1,024	0,637	1,359
1991	1,021	0,623	1,389
2001	1,023	0,616	1,446

Table 2: Value of β, estimation on urban agglomerations, descriptive statistics.

This is consistent with the results on municipalities.

Tuscany and other Italian regions In order to describe the relative degree of polycentricity of Tuscany as compared to other italian regions rank-size estimations were computed for every regions, by taking into account Census data (legal population) from 1971 to 2001. These estimations allow also to see the trends of spatial structure overall Italian territory.

Again, rank-size estimations were iterated by considering the biggest cities, from the 15 to the 150 biggest municipalities.

The following tables show the results of estimation for the bigger

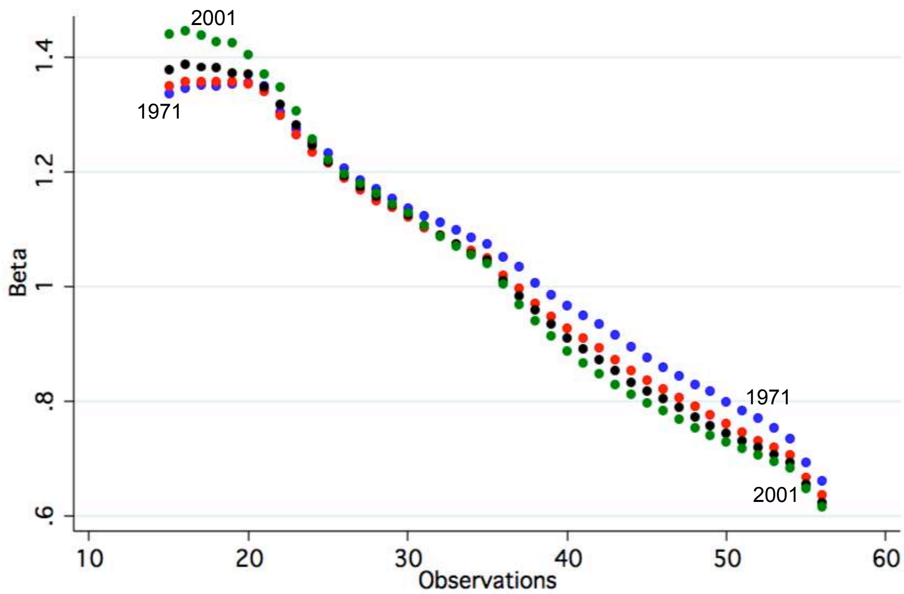


Figure 6: Rank-size estimation on urban agglomerations, Tuscany

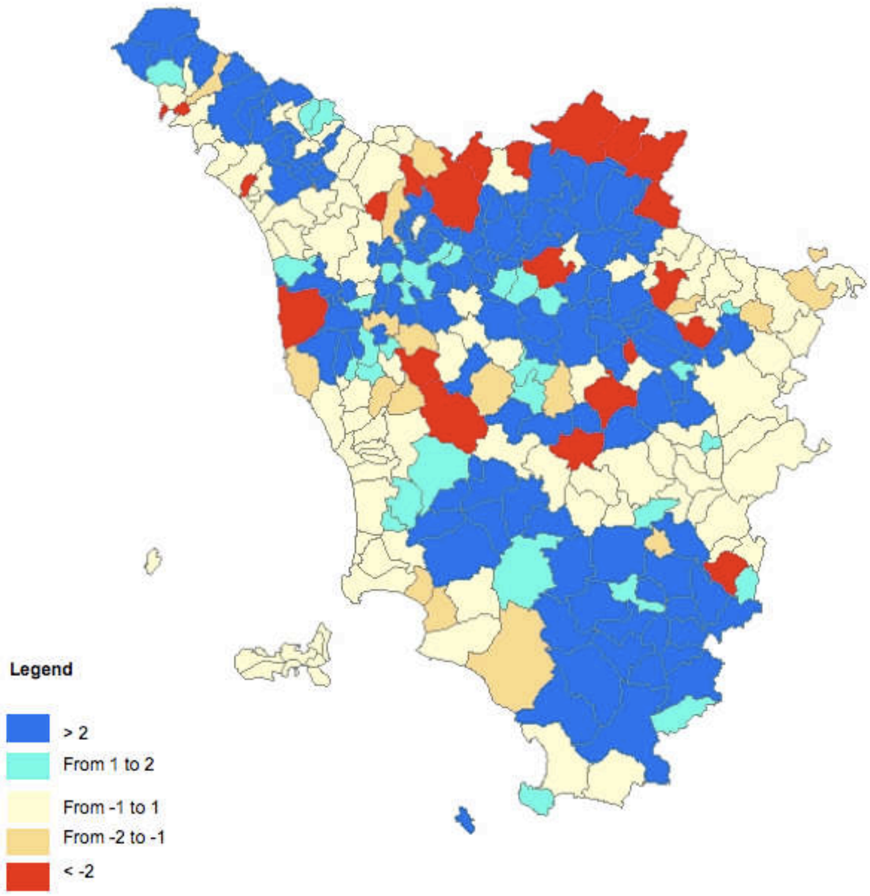


Figure 7: Values of Local Moran's I Statistics, 1971-2001.

Figure 8: Changes on the level of polycentricity in Italian regions, 1971-2001.

25, 35, 50, 100 and 150 cities. Tuscany appears to be one of the most polycentric regions, by considering the biggest 25 cities for each region. The results of the estimations show also that the dynamics towards decentralisation is a general trend of Italian regions. In fact, 10 regions show an increasing β on the entire range of observations, 2 regions show the opposite pattern, while the remaining 8 regions show an increase of β taking into account biggest cities and a decrease if one considers a bigger sample (see Figure 8).

	1971	**1981**	**1991**	**2001**
Puglia	1,29	1,29	1,36	1,44
Marche	1,23	1,26	1,3	1,33
Toscana	**1,15**	**1,18**	**1,22**	**1,27**
Basilicata	1,48	1,35	1,29	1,24
Abruzzo	1,1	1,12	1,17	1,22
Valle d'Aosta	1,08	1,1	1,13	1,16
Campania	1	1,05	1,12	1,16
Calabria	1,1	1,1	1,11	1,15
Sardegna	1	1,03	1,06	1,13
Veneto	0,96	1	1,04	1,08
Sicilia	1,01	1,02	1,07	1,08
Lombardia	0,96	1	1,04	1,06
Piemonte	0,97	0,99	1,03	1,05
Molise	1,28	1,14	1,07	1,05
Friuli-Venezia Giulia	0,91	0,95	0,99	1,04
Umbria	0,96	0,97	0,98	1
Trentino	0,93	0,93	0,96	0,99
Emilia	0,92	0,93	0,96	0,99
Liguria	0,81	0,83	0,84	0,85
Lazio	0,72	0,73	0,75	0,78

Table 3: Rank-Size estimations, top 25 cities, Italian Regions

	1971	1981	1991	2001
Veneto	1,21	1,27	1,33	1,4
Puglia	1,31	1,32	1,35	1,38
Lombardia	1,17	1,23	1,3	1,34
Campania	1,17	1,2	1,27	1,32
Calabria	1,31	1,26	1,27	1,25
Trentino	1,24	1,22	1,22	1,24
Sicilia	1,19	1,19	1,22	1,22
Toscana	**1,14**	**1,15**	**1,17**	**1,21**
Friuli-Venezia Giulia	1,2	1,2	1,21	1,21
Basilicata	1,36	1,29	1,23	1,17
Piemonte	1,06	1,1	1,13	1,16
Sardegna	1,26	1,2	1,18	1,16
Molise	1,38	1,24	1,17	1,13
Emilia	1,01	1,04	1,07	1,11
Marche	1,07	1,06	1,07	1,09
Abruzzo	1,21	1,12	1,1	1,08
Lazio	0,99	0,99	1,01	1,04
Liguria	0,9	0,91	0,93	0,95
Valle d'Aosta	0,88	0,82	0,8	0,77
Umbria	0,78	0,74	0,73	0,71

Table 4: Rank-Size estimations, top 100 cities, Italian Regions

IV.B. Functional Polycentricity

IV.B.i. Data and their treatment

The data used in this section refer to the daily commuting trips (*house-to-work*) for job purposes among the 287 municipalities of Tuscany. The source is the General Census of Population (year 2001).

The data represent the flows from each municipality of origin to each destination, in the form illustrated by table 5.

Origin	Destination	Commuters
1	1	x_{11}
1	2	x_{12}
$\vdots$	$\vdots$	$\vdots$
2	1	x_{21}
$\vdots$	$\vdots$	$\vdots$
L	1	x_{L1}
$\vdots$	$\vdots$	$\vdots$
L	L	x_{LL}

Table 5: Commuting flows between municipalities, structure of the dataset.

From the original dataset, an origin-destination matrix (OD) was generated, representing the flows in the following form:

$$OD = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1L} \\ x_{21} & x_{22} & \dots & x_{2L} \\ \vdots & \vdots & \ddots & \vdots \\ x_{L1} & x_{L2} & \dots & x_{LL} \end{bmatrix}$$

By using the OD matrix together with the coordinates of each municipality, a map of the flows was generated by using the software Tobler's Flow Mapper, which allows to visualise the links between cities. [25]

Finally, the indexes of spatial interaction referring both on the entire system and the cities were computed. The latter were also represented in maps by using the software ArcGis.

[25]The software Tobler's Flow Mapper is available for the download at the web page `http://www.csiss.org/clearinghouse/FlowMapper/`.

IV.B.ii. Findings

Figure 9 illustrates the commuting flows between the municipalities in Tuscany. As shown by the map, the biggest share of the flows appears in the northern area of the region, where the main nodes are located. A large amount of flows, in particular, involves the metropolitan area of Florence, which is the most inhabited zone in the region (around 1 500 000 habitants, almost half of the population).

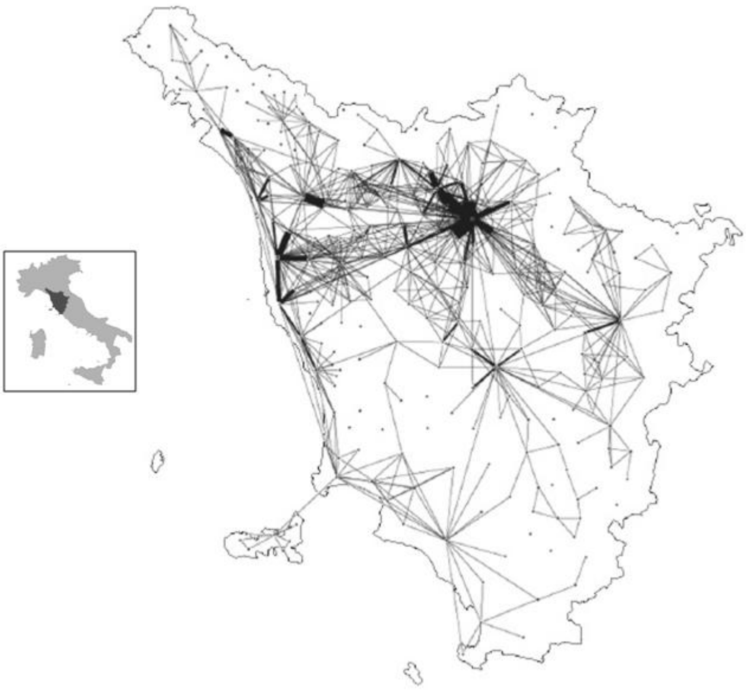


Figure 9: Commuting flows in Tuscany, year 2001.

However, the structure appears to be not totally monocentric, but seems to be, at least, characterised by two main urbn agglomerations. In fact, a large amount of flows appears in the western part of the region, the coastal area, where other important centres are located, like Pisa, Livorno and Massa Carrara. Minor centres appear in the southern coastal area (Grosseto area) and around the towns of Siena and Arezzo (East of the Region).

The interaction indexes were computed in order to measure structure, strength and symmetry of interaction. Table 6 shows the results.

Index	Value		
Entropy in-commuting	0.78		
Entropy out-commuting	0.83		
	Mean	**Median**	**St. dev.**
Node Symmetry	− 0.113	− 0.1001	0.159
Dominance	1.033	0.324	3.256
Relative Strength	0.0075	0.0002	0.0978

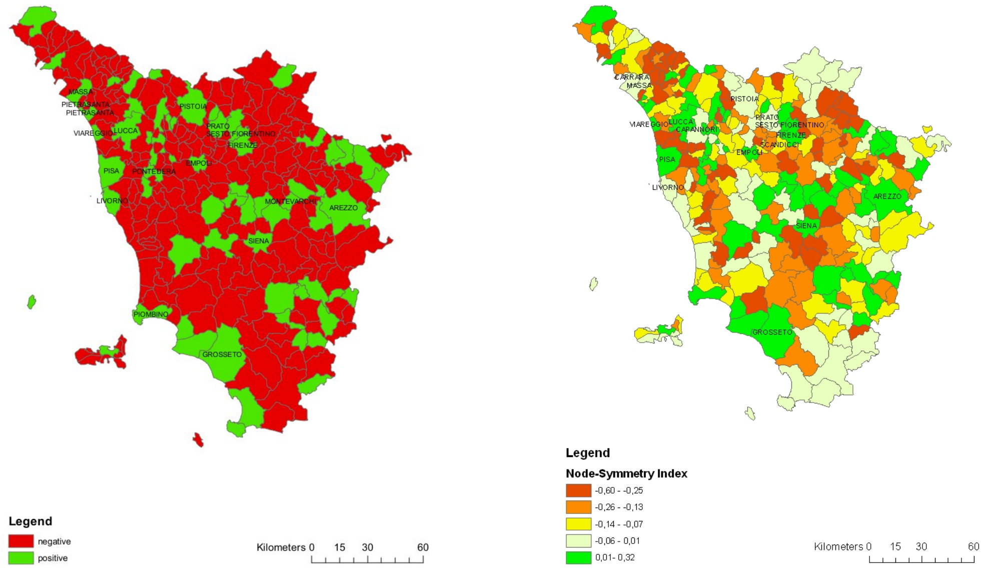
Table 6: Interaction Indexes in Tuscany, descriptive statistics.

Structure The entropy indexes indicates a quite polycentric structure of flows, as the values are considerably high. So, according to the *structural* aspect of interaction, Tuscany might look as a polycentric system, since the total interaction involves a wide range of centres: the spatial system appears to be quite integrated.

It is noticeable that out-commuting is index is higher than in-commuting: this indicates that residential activity is more dispersed than the job market centres (the latter concentrated in bigger cities).

Symmetry and strength of the centres Once recognized that the structure of the system appears to be polycentric, a further step is to consider the *directions* of flows, in order to see what are the main centres attracting transfers from other cities.

Figure (a) shows the balance betweenin-commuting and out-commuting in municipalities. As expected, (Figure10) the main cities are characterized by positive net commuting (i.e. they attract people from the other municipalities), while the minor centres shows a deficit. It might appear quite surprising that some small municipalities, especially in the central and in the southern parts of the Region, have a positive balance. The latter is probably due to high degrees of *self-containment* of these municipalities, whose economy is based mainly on agricolture and poorly connected (with infrastructures) with the main centres. Also some municipalities on the borders are characterised by positive balance: that is probably due to the commuting towards municipalities in other regions (excluded from the dataset).



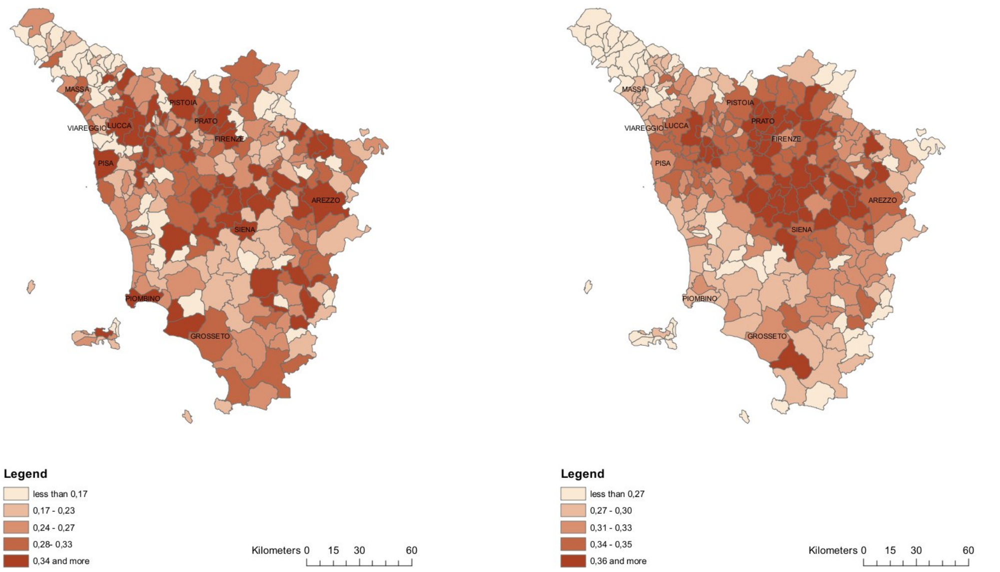
(a) *Balance between in-commuting and out-commuting.*

(b) *Node - Symmetry Index.*

Figure 10: Symmetry, Tuscany

The Node-Symmetry Index, illustrated in Figure 10 (b), presents an average value of -0.113 and a median of -0.10. According to that, the structure appears to be polycentric: even if the average city presents a deficit of commuting, the fact that both average and median values are close to zero seems to indicate a quite polycentric structure. So, even if main cities attract flows from their surroundings, it can be inferred that the job markets are quite evenly distributed (see also Figure 10 (b)). This distribution is linked to the fact that the economic structure of the region is constituted by many productive clusters, the so called *industrial districts* (Becattini et al., 2003). Those are located not only in the main cities, but also in the smaller settlements: this peculiarity has been made the Tuscany of example of dispersion of economic activity on space, as well as other regions in the Central and Eastern Italy (Boschma, 2005; de Dominicis et al., 2007).

However, it is the Northern-Central area that dominates the economic structure of the Region, especially towards the main cities. This is shown by the ratio between in-commuting and out-commuting on population (Figure 11). The high values in the central part of Tuscany are probably due to high-levels of self containment.

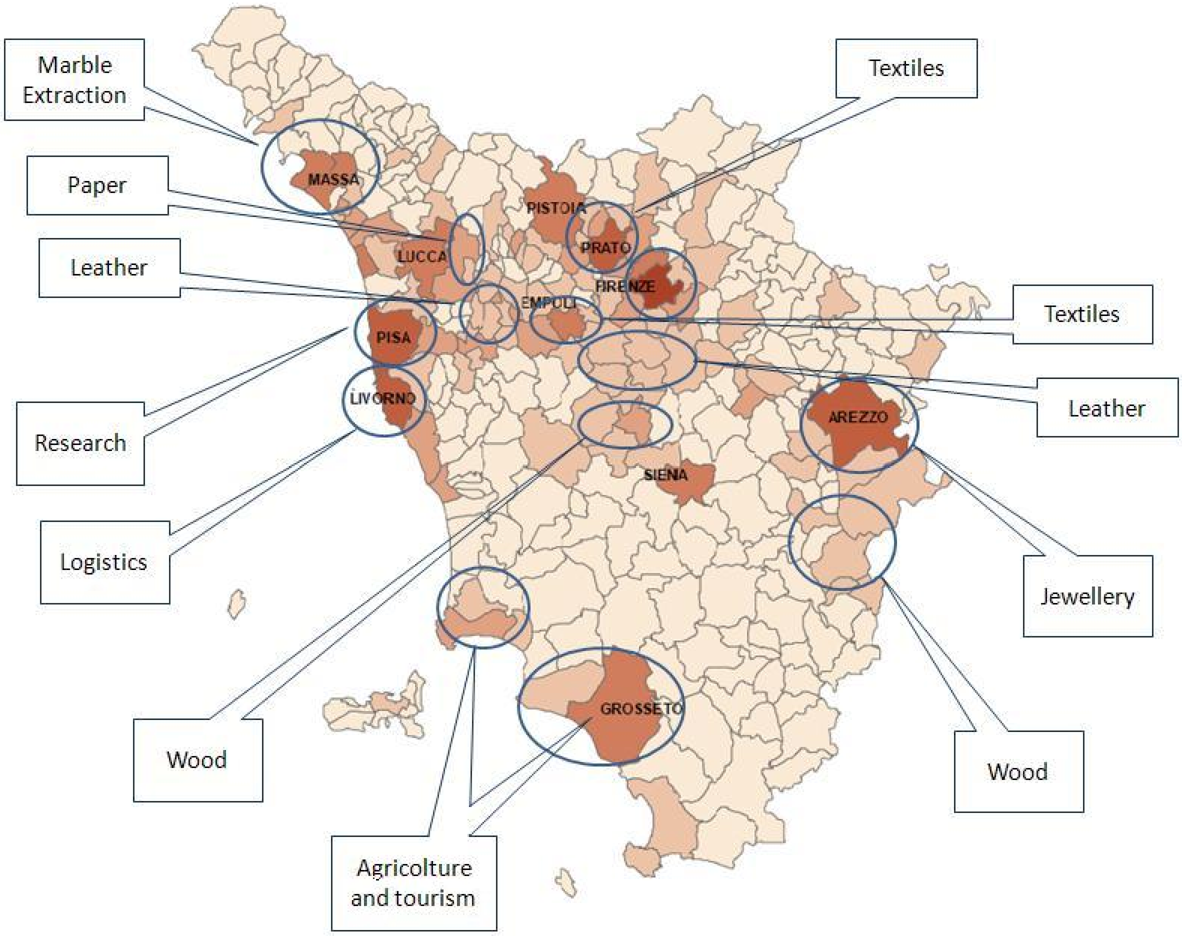


(a) *Ratio between in-commuting and population.* (b) *Ratio between out-commuting and population.*

Figure 11: In-commuting and out-commmuting normalized by population, Tuscany

As Figure 12 shows,the area of Florence and Prato on the one hand, and the coastal area (Pisa, Livorno and Massa) on the other hand, have the biggest dominance indexes. In the middle of these two areas there are many municipalities characterised by intermediate values: these are the settlements in which is located the majority of the manufacturing clusters (with high specialisation). This allows to define the region as a polycentric system.

Figure 12: Dominance Index and main industrial clusters, Tuscany.



V. Concluding remarks

The question that motivated the research reported here was to investigate the spatial structure of Tuscany with reference to its degree of polycentricity. In order to deal with this question, some general aspects had to be preliminary analysed and discussed. For this reason the paper is divided into two theoretical sections (2 and 3) and an empirical one (sect. 4). The methodological questions related both to the assessment of the benefits and costs of polycentricity (normative issue), and to its definition and measurement (positive issue); in other words, the questions were i) whether polycentric development can achieve more general policy goals, ii) which are the dimensions involved into the concept of polycentricity, and iii) how to use morphological and functional indicators in order to measure it.

The first question, the normative one, was analysed in section 2. Polycentric structures are often claimed to have beneficial implications for economic efficiency, regional disparities and environmental sustainability. Also the European Commission (1999) maintained that polycentricity helps in achieving the goals of EU policies. By reviewing the existing literature, section 2 showed that inquiries into this issues are few and that no exhaustive answer exists about the supposed benefits of polycentric development. The uncertainty about the benefits of polycentricity is strongly related to the fuzziness of its definition, which is far from being univocal. Section 3 investigated the definition issue and shows that its vagueness depends mostly on the complex and multi-dimensional nature of polycentricity. The several aspects defining it are commonly distinguished in morphological and functional ones, two dimensions that are, however, mutually related to each other. The present study focused on the distribution of population (morphological dimension) and the flows of commuters between centres (functional dimension). This also helped to highlight the relationship between polycentricity and the territorial patterns of economic specialisation. Section 3 also tackled the issue of measuring polycentricity. The literature usually measures morphological polycentricity by rank-size estimations of population in the centres (both in absolute terms and density). Rank-size estimations provide a synthetic value of the degree of polycentricity in regions, allowing also for cross-sectional and time comparisons. With reference to the functional dimension, some indicators used in the literature were described and analysed. They refer to flows between centres in terms of their structure, strength and symmetry. In particular, daily house-to-work movements represent one of the most prominent forms of interaction between cities and have been used by the literature to define functional urban areas. Thus, interaction indicators allow to investigate the multidirectional relationships between centres and to define polycentric regions as integrated and systemic. They also enable to infer the different roles played by the centres and the peripheries.

The empirical part (section 4) applied the methodological framework developed in section 3 to explore polycentricity of Tuscany. This region is usually held as polycentric because it is characterised by the presence both of medium sized centres and of industrial clusters spread in the territory (also outside the main cities). Moreover, polycentricity has recently become a goal of regional spatial planning policies. In order to explore the morphological dimension of polycentricity, rank-size coefficients were estimated for the years 1971, 1981, 1991, 2001. Estimations have been carried out for all Italian regions by taking into account both municipalities and urban agglomerations. Results showed a trend of decentralisation in regions, that is, a reduction of the size of the main cities. In order to explore the functional dimension the indexes of commuting presented in section 3 were computed for the year 2001 for municipalities in Tuscany. The analysis showed how the spatial interaction is still bounded by proximity and by the dominance of the main centres. In other words, the largest share of interaction is between the main centres and their neighbourhoods, so that the former keep their role of engines of economic development, while the smaller centres (the periphery) are characterised by the residential activity, which is increasing, as suggested by rank-size estimations. At the same time, it also emerges that some small centres, those where important industrial districts are located, attract workers, and hence residents and commuters. The analysis showed that the morphological dimensions and the functional ones are closely linked to each other and allow, taken together, to conclude that Tuscany is characterised by a high degree of polycentricity, both in absolute terms and as compared to the other Italian regions.

This paper highlighted that polycentricity is a multi-dimensional concept, characterised by several dimensions. The study focused on the distribution of population and the spatial interaction while some other characteristics of polycentric regions were not explicitly taken into account. Firstly, the clustering and specialisation of economic activity over space was not considered. The reason is that there are already many studies devoted to this issue. Secondly, because of the lack of data, the commuting patterns were studied for a single year. Moreover, it was not possible to compare Italian regions as regard the functional dimension since data about commuting flows were available to the author only for Tuscany. Of course, commuting for job-purposes, even if is one of the most prominent phenomena of spatial interaction, does not exhaust the interrelationships between cities. The latter could be described by other indicators, like flows of money, information, migrations, etc. Further research should consider those other measures.

Finally, the relationship between polycentricity and land use, particularly the open space between centres, is a still open issue, both in theoretical and empirical studies. In fact, the literature remarked how polycentric development and urban sprawl are opposite in theory (having also very different implications on economic welfare and environmental sustainability), but very difficult to distinguish in empirical analyses with the standard tools, those described and used in this paper. The actual benefits of polycentric development can be understood only after having solved this difficulty.

To sum up, the present paper analysed the spatial structure of Tuscany by combining several aspects involved in the definition and measurement of polycentricity. Such a research strategy is not common in the literature, however it helps reducing the risk of partial views of a phenomenon that is, by its very nature, complex and multi-dimensional.

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