SPATIAL STRUCTURE AND ECONOMIC DEVELOPMENT: THE CASE OF ITALY

David Burgalassi

Tesi di Dottorato

Università di Pisa

Dipartimento di Economia e Management

Dottorato di Ricerca in Economia Politica

Settore Scientifico-Disciplinare

SECS P/06 –Economia Applicata

Direttore della Scuola di Dottorato	Tutor
Prof. Davide Fiaschi	Prof. Tommaso Luzzati

Commisione giudicatrice:

Prof. Roberto Camagni (Presidente), *Politecnico di Milano*
Prof. Henri L.F. de Groot, *Vrije Universiteit Amsterdam*
Prof. Mario Morroni, *Università di Pisa*

Pisa, Settembre 2014

SPATIAL STRUCTURE AND ECONOMIC DEVELOPMENT:

THE CASE OF ITALY

David Burgalassi

PhD Dissertation submitted to the Department of Economics and Management

University of Pisa

in fulfilment of the requirements for the degree of

Doctor of Philosophy

in

Economics

Department of Economics and Management

University of Pisa

September 2014

Abstract

The aim of this thesis is contributing to the debate about the organization of economic activities across space and its impact both on economic competitiveness and on environmental sustainability.
The first chapter states the most important aspects of spatial structure, which are polycentric development and urban dispersion, and highlights the relevance of spatial economic organization for public policies, in particular with reference to the spatial policies addressed by the European Union.
In order to assess the effects of spatial structure, the second chapter tackles the issue of the analytical definition and measurement of polycentricity and dispersion. By surveying the most relevant literature in urban and regional economics, and geography and spatial planning, the chapter illustrates the main analytical dimensions and the empirical methods for the measurement of spatial structure at regional level, providing an empirical illustration on Italian regions.
The third chapter analyses the relationships between spatial structure and economic competitiveness in Italian NUTS-3 regions. It presents the theoretical framework, grounded on agglomeration economies literature, and checks whether agglomeration economies may depend on spatial organization of economic activities across Italian regions. In the empirical analysis labour productivity is taken as a proxy for economic competitiveness and both polycentricity and urban dispersion are shown to have negative impacts.
The fourth chapter analyses the links between spatial structure and environmental pressure. The latter has been measured by gas emissions generated by private road transport and house heating. After the literature review, the chapter shows, through regression analysis of NUTS-3 regions, that spatial structure influences CO_2 emissions from transport and PM_{10} emissions from house heating, with no evidence that polycentricity helps in reducing emissions.
The thesis concludes discussing the main results from the empirical part of the work and sketching further steps in the analysis of spatial structure and economic development.

JEL classification
O18 - Urban, Rural, Regional, and Transportation Analysis
R11 - Regional Economic Activity: Growth, Development, Environmental Issues, and Changes
R12 - Size and Spatial Distributions of Regional Economic Activity
R14 - Land Use Patterns
O47 - Aggregate productivity
Q53 - Air Pollution

Keywords
Spatial structure
Agglomeration economies
Urban regions
Polycentricity
Urban dispersion
Regional development
Regional competitiveness
Labour productivity
Environmental pressure
Gas emissions

Contents

PART I

PART II

List of tables

List of figures

PART I

1 Introduction

This thesis aims to analyse the relationships between spatial structure and urban/regional economic development, with a special focus on the empirical evidence that can be drawn for Italy. The work is based on urban and regional economic analysis, in particular on agglomeration economies, a phenomenon which has been recognised as one of the most important drivers for development of cities and regions. In particular, the thesis investigates whether agglomeration advantages may be linked to the spatial organization of economic activities across Italian urban regions. The work focuses on two major aspects of spatial structure, polycentricity and urban dispersion, which show increasing interest both in the academic literature and territorial policies, and require more empirical analysis. This introductory chapter sets the theoretical framework, provides the research questions and presents polycentricity and urban dispersion, describing their (supposed) role for urban and regional development. This chapter and the entire thesis give particular attention to polycentricity, since it has become a key tool addressing spatial policies of European States.

1.1 Spatial distribution of economic activities and agglomeration economies

In 2005 T. L. Friedman argued that the “world is flat” (Friedman, 2005), telling about the “death of distance”. Accordingly, many aspects of globalisation – such as technological and organizational changes – caused increasing irrelevance of geography and distance for economic agents. Hence, in a world fully connected proximity is no longer important. However, those propositions are far from being verified. Economic activity appears to be increasingly concentrated. In his popular reply to Friedman’s work, R. Florida (2005, p. 48) wrote that the “World is spiky” giving some facts illustrating that “surprisingly few regions truly matter in today’s global economy” and that “the tallest peaks – the cities and regions that drive the world economy – are growing even higher, while the valleys mostly languish”. Hence, population and economic activities are far from being evenly distributed across space. On the contrary, economic production has become increasingly concentrated, especially at smaller spatial scales, such as within countries (World Bank, 2009). The more innovative activities are even more concentrated, while mature industrial sectors have been moved mainly towards developing economies. Income levels, growth rates and distribution show significant spatial heterogeneity. This holds also in Europe: many stylized facts confirm that European countries are characterised by strong heterogeneity in economic concentration and specialization of their regions (Combes and Overman, 2004). Additionally, patterns of convergence have substantially differed between and within countries, which have often showed patterns of polarization. Italy confirms the evidence that economic activity is characterised by patterns of geographical concentration in many economic sectors (De Dominicis et al., 2013).

Hence, even in a globalised world, distance and proximity do matter for economic development, and economic activities are “much more clustered than would be expected if location was the result of a random outcome” (Puga, 2010, p. 203). Actually, the main clusters of economic activities are represented by cities, which are the engines of economic growth for regions and countries. Compared to other areas, cities present some advantages for firms and workers, which have been recognised in early economics works, such as in Smith (1776) and especially in the *Principles of Economics* book by Marshall (1890), and then stimulated a huge amount of research during the last century. The interest in agglomeration advantages as drivers for urban and regional (endogenous) growth increased especially in the last two decades, with the advent of ‘New growth theories’ (Lucas, 1988) and the ‘New Economic Geography’ (Krugman, 1991, 1995; Fujita et al. 1999). Economic research approached the economic advantages of cities mainly by showing that (Puga, 2010):

1. The spatial distribution of economic activity is highly clustered;
2. Wages and land rents differentiate across space; cities show higher values, which should reflect some advantages;
3. Productivity is higher in cities.

The drivers of the advantages of cities and urban environments are represented by agglomeration economies, which, starting from Marshall (1890) have been the subject of an increasing amount of theoretical and empirical research, especially in the last decades. Agglomeration economies can be defined as positive externalities, i.e. advantages for the economic agents that are usually based on their geographic or relational proximity (Duranton and Puga, 2004). When taking into account the production processes, agglomeration economies can refer to single firms (scale economies), to the clustering of firms within the same industry (localisation economies), or to the proximity of economic agents from different sectors (urbanisation economies).[1]

The literature that has approached localisation economies states that proximity of similar or related industries enhances innovation processes and growth through mechanisms of cooperation – Marshall-Arrow-Romer externalities (Combes, 2000) – or competition – Porter externalities (Porter, 1990) – among economic agents.[2] According to urbanisation economies theories, proximity is maximised in cities, where density and size of economic activities are high and foster mechanisms of 'sharing' of information and ideas, 'matching' of job supply and demand and 'learning' processes by the workforce (Duranton and Puga, 2004). Urbanization externalities appear to be relevant for innovative activities and high-tech sectors (De Groot et al., 2009).

1.2 Evolution of urban systems, spatial structure and the scope of agglomeration economies

Notwithstanding the differences between the main theoretical and empirical approaches to agglomeration economies, size and density have been assumed as the main proxy of agglomeration. In particular, urbanisation economies have been assumed to be an increasing function of scale and density – up to a certain threshold – and a decreasing function of the distance from the urban cores (Rosenthal and Strange, 2004). Agglomeration economies within industries (static localisation and dynamic MAR externalities), which may regard small and medium sized firms, do require an aggregate critical mass to exploit.

However, urban regions have been subject to huge changes in their structure in the last decades. Cities expanded their geographical scope and (especially in Europe) new functional urban regions – or cities *de facto* – arose as result of territorial coalescence of pre-existing self-contained cities (Calafati and Veneri, 2013). These phenomena give rise to patterns in the spatial structures of urban areas that are definitely more complex than the simple physical expansion of cities and they might influence economic activities and relationships occurring within and between cities. Two main aspects that have been identified are urban dispersion and polycentricity (Anas et al., 1998).

One of the most evident features of contemporary urban region is represented by

[1] Another distinction can be made between static and dynamic externalities. The former affect the level of productivity, and can be related to scale of production (scale economies), industrial advantages (localisation externalities) or aggregate demand and variety (urbanisation externalities). The latter affect knowledge spillovers – hence innovation and growth.

[2] For a discussion of the sources of agglomeration economies, see Glaeser et al. (1992). For a meta-analysis, see De Groot et al. (2009). For an application to Italy see Cirilli and Veneri (2011).

suburbanisation and related urban dispersion, or urban sprawl. The massive structural changes caused by the Industrial Revolution, with both the demographic and urban transition, led to the physical expansion of cities, which increased their role as engines for regional economic growth (Hohenberg and Lees, 1985). Technological improvements in urban and interurban transport driven urban expansion

In the early 20th century Geddes analysed the changes in the urban forms – as cities evolved into urban areas and eventually into conurbations (Geddes, 1915). During the 20th Century urban dispersion interested most of the urban areas, affecting American cities firstly and then European ones driven by several factors, including growth in incomes, technological progress in transport systems, change of preferences, demographic change and migration (Anas et al., 1998).

A second feature that characterises contemporary urban region is polycentricity: that is the presence of several economic centres within urban areas and regions, which can be characterised by interaction and mutual interdependencies. In some cases polycentricity has been driven by patterns of re-clustering of activities. If in the past the Central Business District (CBD) was a major focal point of the urban economy (Alonso, 1964; Muth, 1969; Mills, 1972). In recent decades economic activities have re-clustered in new sub-centres within the same urban region. In other cases polycentric urban regions have been the result of pre-existing centres that became more interconnected. This pattern has been found mainly in European urban systems, which typically show high land constraints and the poor availability of open space. In Europe, cities are traditionally linked to each other, with high relational densities and a physical proximity (Calafati, 2009). Thus, physical growth in cities has appeared more in the form of the coalescence of existing centres rather than the emergence of new cities, while in other cases, such as in American regions, new centres are likely to be built.

Given the above-mentioned dynamics, for more than thirty years, spatial structures and economic performance have been recognized as being strictly linked to each other (Parr, 1979; 1987). A hypothesis that has been proposed is that the dynamics of change in urban regional systems have been linked with a 'regionalisation' of agglomeration economies (Meijers and Burger, 2010). Regional development can be fostered by localised network externalities (Boix and Trullén, 2007), which for instance can be generated by the networking between "major agglomerations and their hinterland" and by "dense networks of big or middle sized cities" (Barca, 2009, p. 18). Those externalities can substitute simple agglomeration externalities and allowing for the emergence of *regionalised* urbanisation economies (Meijers and Burger, 2010). In other words, cities may "borrow" each other's size in order to achieve the critical mass needed to generate agglomeration economies (Alonso, 1973).

However, while there is a consolidated research on the role of size and density for economic activity (Ciccone and Hall, 1996; Rosenthal and Strange, 2004), little attention has been devoted to the "spatial configuration of cities and regions and the geographical scale of agglomeration benefits" (Burger et al., 2010, p. 20). In particular, few studies have investigated the effects on agglomeration economies of other aspects of spatial structure than size and density, such as polycentricity and urban dispersion. The gap between research on agglomeration economies and studies on spatial structure, noticed by Parr in 1979, still exists. This is particularly true when considering the inter-urban spatial level, i.e. the urban region.

However, even if there is no adequate academic endorsement to the role of spatial structure on economic development, the above mentioned ideas represent a theoretical rationale at the basis of current European and National territorial strategies (Commission of the European Union, 2011), especially those promoting polycentric development. This thesis aims to bridge this gap, at least partially, by focusing on polycentricity and urban dispersion. With reference to those two aspects, writers have provided explanations on their role for economic development but, to date, the empirical analysis is quite poor and, when there is, quite equivocal.

1.3 Polycentric development: from a descriptive concept to a normative tool

The above-mentioned ideas of ‘regionalisation of agglomeration economies’ and ‘borrowed size’ represent now a theoretical rationale at the basis of current European and National strategies promoting polycentric development, especially in the European context.

The notions of polycentricity and polycentric development have been traditionally applied at the intra-urban level, which is the study of cities. In land planning, polycentriciy began to be studied as a characteristic of cities in alternative of the monocentric model, while at the inter-urban spatial scale, which is the spatial level addressed by this thesis, the literature focused on the concept of “Polycentric Urban Region” (PUR) (Parr, 2004), and some European regions characterised by pronounced polycentricity were identified.

The archetypal example of a PUR is the Randstad Region, in the Netherlands (Figure 1.1). It is a region composed of four main cities (Amsterdam, Rotterdam, The Hague, and Utrecht), characterised by economic complementarity and highly interconnected in terms of flows. Amsterdam represents a major hub for finance, air transport, and tourism. The Hague concentrates Government and administrative functions. Rotterdam’s economy is rooted in its port. Utrecht is specialised in services and the cultural sector.

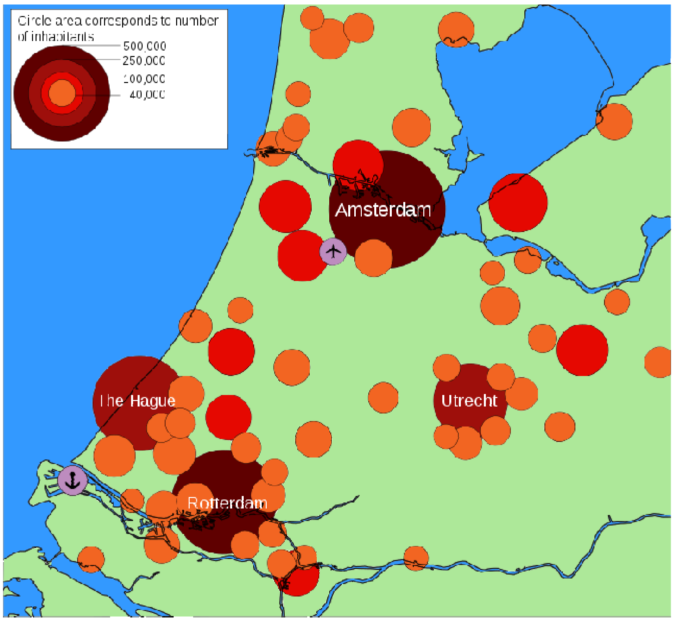


Figure 1.1: The Randstad, the archetypal polycentric urban region
Source: http://en.wikipedia.org/wiki/Randstad

Another example of a PUR is the Rhine-Ruhr region in Western Germany, which is one of the largest world conurbations composed of eight cities of similar size (Dusseldorf, which is the largest city, has around 590 000 inhabitants, while Oberhausen, the smallest centre, has 210 000 inhabitants) (Cox, 2013). Other well-known examples of PURs include the 'Flemish Diamond' in Belgium (an area composed by the cities of Brussels, Antwerp, Ghent and Leuven (Albrechts, 2001) and the Venice-Treviso-Padua region in North-East Italy (Camagni and Salone, 1993).

However, since the European Spatial Development Perspective (ESDP) was published in 1999, the concept of polycentric development ceased to be only analytical and began to have a normative relevance as a strategic concept to promote both economic, social and sustainability goals (Davoudi, 2003). The ESDP is the territorial strategy prepared by the Committee on Spatial Development of the European and agreed by the Ministers responsible for Spatial Planning in the Member States of the European Union, with the aim to achieve a balanced and sustainable development of the European Union. Agreed in 1999, it is the result of around a decade of gestation (Schmitt, 2011). Accordingly, one of the main pillars is represented by the "development of a balanced and polycentric urban system and a new rural-urban relationship" (European Commission, 1999).

Polycentricity would promote not only regional growth, through the regionalisation of agglomeration economies, but also cohesion and sustainability. Polycentric development represents a tool for spatial policies, within the general framework of EU policies, such as those established by the Lisbon Strategy (2000), the action plan for the EU.

Spatial policies should foster polycentricity not only within urban areas, but across the whole territory of the EU. The improvement of regional accessibility and the diffusion of information and knowledge represent some pre-condition for polycentric development.

The ESDP has been followed by other policy statements and has stimulated subsequent research on polycentric spatial structures and social, economic and environmental performances. In 2007 the 'Territorial Agenda' came out. The document was strongly rooted on ESDP, and stressed the goal of territorial cohesion, following the general framework stated by the Fourth Report on Economic and Social Cohesion that was launched immediately before (European Commission, 2007). Accordingly, polycentric development is a tool for "making better use of available resources in European regions":

> "We stress that polycentric and balanced territorial development of the EU is key element of achieving territorial cohesion. Where the most developed cities and regions within Europe cooperate as parts of a polycentric pattern they add value and act as centres contributing to the development of their wider regions. Urban development policies also have a significant role in this regard. Polycentric territorial development policy should foster the territorial competitiveness of the EU territory also outside the core 'Pentagon area'. We encourage cities to form networks in an innovative manner, which may allow them to improve their performance in European and global competition and promote economic prosperity towards sustainable development.
>
> At the same time we aim at polycentric development at the macro-regional, cross-border and also on national and regional level in relevant cases. Where possible, it is important to avoid polarization between capitals, metropolitan areas and medium sized towns on the national scale. Small and medium-sized towns can play a crucial role at regional level. Policy efforts should contribute to reducing the strong territorial polarisation of economic performance, avoiding large regional disparities in the European territory by addressing bottlenecks to growth in line with Europe 2020 Strategy."
>
> (European Commission, 2007, p. 4)

The Territorial agenda was then updated with the 'Territorial Agenda of the European Union 2020', agreed between the ministers for spatial planning and territorial development of EU Member States in 2011 (European Commission, 2011). The document has been released in order to adapt spatial policy to the new Economic and Social Agenda of the European Union 2020, the so called 'Europe 2020 strategy' and again stressed the role of polycentric development.

However, despite the general success of *polycentrism* in the policy agenda, *polycentricity* is still a fuzzy and vague concept and its effectiveness still needs to be corroborated with appropriate empirical research (Davoudi, 2003; Meijers, 2008). So far, policies aiming at polycentric development may thus lack a strong scientific rationale, and polycentric development appears to be one of the "code words" of Europe (Clark, 2001): "a coded term but not rigidly codified, ambiguous, with changeable outlines" (Baudelle, 2007, p. 76).

1.4 Urban dispersion and urban and regional development

Urban dispersion is the second relevant dimension of spatial structure that is addressed in the thesis. The concept of dispersion refers to the extent to which economic activities are spatially concentrated in centres or, conversely, evenly dispersed. Hypothetically, we have two polar cases depending on where most of human activity is settled, either concentrated in one (or more) centre(s) or diffused uniformly across the region. Recent dynamics in rich countries have often moved regional structure towards dispersion rather than concentration, generating the so-called "urban sprawl".

The increase in urban dispersion became relevant in North America already in the first half of 20th century due to the revolution resulting from mass motorization (Burchfield et al, 1998). Commuting became cheaper and easier allowing more freedom in the choice of the residential location. People did not anymore need to live close to their workplace or commercial activities and started to relocate out from city cores. Residential relocation firstly involved upper income classes, who first could afford the use of private vehicles. Then, due to the decline in transport costs, also low income households were attracted by the lower land prices of the surroundings (Le Roy and Sonstelie, 1983). The low land prices also made the new settlements to be characterized by extensive land use. Similar dynamics appeared later on in Europe and other areas, where urban growth came together with urban sprawl in the last decades, in particular in the most advanced regions and in areas characterized by rapid economic growth (European Environment Agency, 2006).

Given those dynamics, urban dispersion received increasing attention from economists, planners, and policy makers. Actually, the perception about urban sprawl is mainly negative. Many studies stressed the adverse effects of this pattern of development on the environment (Camagni et al., 2002a, 2002b), given the loss of fertile soil, the increase in traffic due to longer distances and higher use of motorised private transport, the higher energy requirements of 'extensive' patterns of urban development. Opponents of sprawl suggest also that dispersion may cause other adverse economic effects. Dispersion can be related to spatial mismatch between firms and workers (Wheeler, 2001). Additionally, dispersion may weaken agglomeration externalities that characterise dense cities. In dispersed areas chances for informal communication and face-to-face contact are lower, thus reducing possibilities for the exchange of innovative ideas, which are at the basis of the dynamic externalities pointed out by endogenous growth theories. As a result, dispersed cities may be characterised by lower aggregate productivity than concentrated and dense cities. Other effects of urban dispersion may be related to social cohesion: dispersed area have sometimes been linked to urban segregation (Nechyba and Walsh, 2004) and spatial mismatch.

However, there is no agreement on the effects of urban dispersion. Some authors state that urban sprawl is a phenomenon naturally related to urban growth (Gordon and Richardson, 1997). Moreover, dispersed cities can offer many advantages to people and firms, such as low house prices and larger housing lots, and less traffic congestion than dense areas (Gordon and Richardson; Glaeser and Kahn, 2004). According to this view, the negative effects of dispersion on agglomeration economies are far from being verified.

The two opposed views on urban dispersion turn into opposite policy ideas. While opponents of sprawl call for more regulation and strict planning rules aimed to promote compact city policies, such as the movement of 'smart growth', the advocates of sprawl propose a free-market approach.

As for polycentric development, it seems that more research is required to assess the effects of urban dispersion, starting from its definition and measurement, since there is no agreement on that (Galster et al., 2001):

1.5 The spatial dimension of policies and the aspects of urban and regional development: economy, environment, society

As pointed out in section 1.1, the last decades were characterised by strong development of economic theories, especially those related to growth and development, which started to include geographic aspects into their analytical models and empirical tools, emphasizing that *place* matters for national development. However, despite those developments in theoretical and applied analysis, the field of policy implementation had not made significant progress (Barca et al., 2012). While territorial features have been acknowledged to play a key role, development policies have been quite 'place-neutral'. It is often the case that local and regional policies have been characterised by 'isomorphism'[3], when similar or identical strategies have been formulated by different regions, even if highly differentiated in their cultural, social and economic context (Chien, 2008). As highlighted by Barca et al. (2012, p. 137), regional policies had been focused on the sectoral dimension, with top-down decision making. Frequently, strategies imitated successful policies that had been implemented in different regions, with different contexts.

However, in recent years policy has been addressed towards spatial aspects. In the last decades some reports by international organizations including the World Bank (2009) and the OECD (2009a, 2009b) stressed the role of space in economic systems and subsequently the need to re-think economic policies by including the spatial dimension. Meantime, European strategic policies started to develop a 'place-based' approach for regional development policies. This approach to policy is based on the links between economic local context and

[3] The phenomenon of 'isomorphism' has been firstly observed by organizational studies, with reference to the tendency for organizations to exhibit similar behaviour, despite their differentiations (Di Maggio and Powell, 1991)

institutions (Barca, 2009; Barca et al., 2012).

The inclusion of the spatial aspects in regional strategies of the European Union considers a multi-dimensional approach to development. This approach characterises the whole Union since 1986 (Single European Act), when European Union policies have been aimed to improve economic and social cohesion. Later, the Amsterdam Treaty (1997) stated that economic and social progress of the EU should take into account the principle of sustainable development and within the context of the accomplishment of the internal market and of reinforced cohesion and environmental protection, making clear the multidimensional nature of development. In order to reach EU policy goals, it was clear that the spatial economic organization of cities and regions could represent a tool to promote both growth and cohesion, as well as sustainable development. This was the idea underlining the ESDP, which came out in 1999.

The spatial strategies agreed starting from the ESDP, to adopt a multi-dimensional approach to urban and regional development. The ESDP has intended spatial policy ideas, such as polycentricity, as tools to achieve a sustainable spatial development. The idea of sustainability of spatial development relates to three main dimensions: economy, society and environment. The Territorial Agenda (2007) reinforced the need for appropriate territorial actions to promote the more general sustainable development (Figure 1.2).

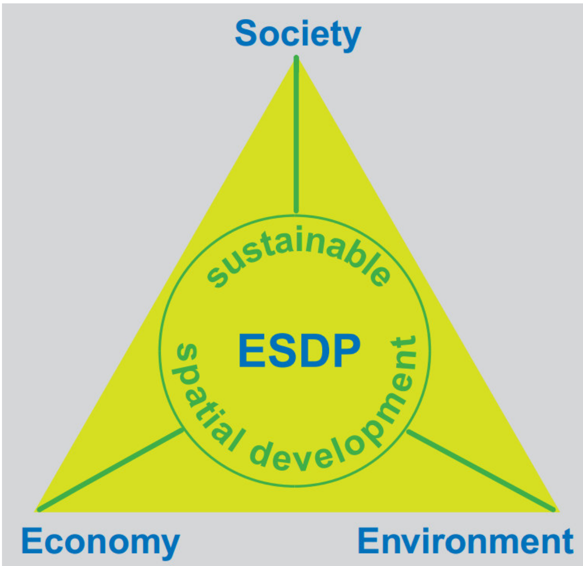


Figure 1.2: Triangle of Objectives: a Balanced and Sustainable Spatial Development
(Source: ESDP, 1999, p. 10)

However, after the Amsterdam Treaty and the ESDP, still Union sectoral policies had no clearly defined spatial goals. The Lisbon Treaty (2009) and the subsequent 'Europe 2020' Strategy for the period 2010-2010 (which replaced the 'Lisbon Strategy') introduced territorial cohesion as a policy goal, together with economic and social cohesion. According to Europe

2020 Strategy, Europe should aim to achieve smart, sustainable and inclusive growth. This goal should be reached by more effective investment in education and research (smart), the switch to a low-carbon economy (sustainable) and with emphasis on employment creation and reduction of poverty (inclusive). The strategy focused on goals to be reached by 2020, with reference to employment (75% of population aged 20-64 should be employed), innovation (3% of European GDP should be invested in research and development), climate and energy (gas emissions should reduce by 20% compared to 1990 levels, the share of renewable energy should be 20% of the total energy sources, energy efficiency should increase by 20%), education (the share of early school leavers should be under 10% and at least 40% of young population should have a tertiary degree), poverty reduction (20 million less people should be at risk to be poor).

The 'Territorial Agenda Europe 2020' (2011) reflects the goals of the Europe 2020 Strategy, stating the territorial priorities for the EU:

1. polycentric and balanced territorial development;
2. integrated development in cities, rural and specific regions;
3. territorial integration in cross-border and transnational functional regions;
4. competitiveness of the regions based on strong local economies;
5. territorial connectivity as pre-condition for cohesion;
6. managing and connecting ecological, landscape and cultural values of regions.

The Europe 2020 Strategy and the Territorial Agenda Europe 2020 are linked to each other, and show the increasing priority given to the exploitation of territorial strengths in order to enhance the sustainable and inclusive development of the entire Union. This includes how to deal with agglomeration and cities, since urban areas increase productivity and innovation, but also show negative effects, such as pollution and social segregation. The place-based approach is explicitly mentioned by the Territorial Agenda Europe 2020 in order to reach territorial cohesion.

To sum up, as addressed by EU strategies, policies have increasingly spatial dimensions, whose effects should be analysed in the multi-dimensional light of the Europe 2020 strategy: competitiveness, sustainability and cohesion. This thesis adopts a multi-dimensional approach, by looking at competitiveness and sustainability of regions, investigating how spatial structure could affect those dimensions. For time and data constraints territorial cohesion has not been explicitly taken into account. However, the conclusions of the work will give some insights on the relevance of the topic.

1.6 The case of Italy and the units of analysis

When investigating the links between spatial structure and development, Italy represents one of the most interesting case studies in Europe. Italian regions and local areas have been a playground for regional and urban economists and geographers for a long time, for many reasons. Italian regions show huge heterogeneity in their economic contexts. The most well-known phenomenon is probably the economic divide between North and South, which became evident after the reunification of the Country in 1861. The question of 'Mezzogiorno' has been addressed by many policies starting from the second half of 20th century, aimed to industrialization and development of southern regions, but the gap with Northern regions still exists (La Spina, 2003).

Another phenomenon that characterised Italian economic development is the rise of the 'Third Italy', that is the set of regions of Central and North-Eastern Italy, driven by a cluster of small and medium-size enterprises which, despite their size, succeeded in being internationally competitive. This form of development stimulated a huge amount of literature about local development and the role of industrial districts for regional growth (Becattini, 1979; Sforzi, 1990). In addition to regional heterogeneity, Italy is also characterised by pronounced variety within regions (Calafati, 2009): hence, local factors appear to be at least as important as regional factors in the analysis of development.

The third relevant phenomenon is the noticeable urban development that characterised Italy. Italy has historically shown high degrees of urbanization (Malanima, 2005). However, the industrial take-off after the Second World War was coupled with huge urbanization process – so that according to some authors the country showed a 'territorial revolution' (Calafati and Veneri, 2011). Urban areas developed by means of city growth and territorial coalescence, which changed dramatically the spatial organization of economic activity. Nowadays cities and urban areas are increasingly integrated in terms of functions and mutual interactions: this is evident for instance in daily commuting flows.

Within this context, the aspects of spatial structure are increasing their relevance. Polycentricity, which is a feature that characterises some of the Italian regions, especially in central and north eastern Italy, has also entered in some regional policies, such as of Tuscany in Central Italy (Tuscany Region, 2005).

At the same time, urban dispersion is causing increasing concerns. As noticed by Camagni et al. (2002b), Italian urban areas have been characterised in the last decades by a phenomenon of scattered urbanization, while during the 1950s and the 1960s urban expansion had been characterised by relatively compact interventions. The phenomenon interested not only large cities, but also small and medium sized towns. Figures about Italy illustrate that urbanised land in Italy grew dramatically in the last decades. During the 1950s, urbanised land occupied 2.9% of Italian surface. In 1996 the value was doubled. In 2012, urbanised land occupied 7.3% of total Italian land. This trend has been particularly evident in the last 20 years, when urbanised land increased by around 1/3. Land use patterns have been characterised by extensive land use, since the per capita urbanised surface grew by 30% (Table 1.1).

Table 1.1: Urbanised land in Italy

	Fifties	1989	1996	1998	2006	2009	2012
Urbanised land (%)	2.9	5.4	5.9	6.1	6.8	7.0	7.3
Urbanised land (km^2)	8 700	16 220	17 750	18 260	20 350	21 170	21 890
Per capita urbanised surface (m^2/pop)	178	286	312	321	350	359	369

Source: ISPRA, 2014

The empirical part of the thesis (Chapters 3 and 4) takes into account Italian NUTS-3 regions (*province*) as elementary units of analysis in assessing the role of spatial structure for economic competitiveness and environmental sustainability respectively. Provinces are administrative units that are intermediate between the NUTS-2 level represented by regions (*regioni*) and the NUTS-4 level of municipalities (*comuni*).

The literature has pointed out how crucial is the choice of the units of analysis for the outcome of applied regional analysis. Hence, a change of spatial units might lead to a change in analytical results: this is the well know Modifiable Areal Unit Problem (MAUP). This problem can be related either to the aggregation of smaller units into larger areas or to the definition of areal boundaries (Openshaw and Taylor, 1979; Burger et al., 2010). Even if no general solutions have been found to solve the MAUP, the general advice is to take into account functional areas as units of analysis. In Italy this could be possible, by selecting functional data, such as the Local Labour Systems, which are local areas defined by commuting flows, or Functional Urban Regions. However, those spatial levels also present some drawbacks, such as the poor data availability (especially with reference to economic data) and impracticality of international comparison. Hence, the studies on European regions and urban areas often use either NUTS-2 or NUTS-3 level.

Provinces (NUTS-3) are administrative units. Notwithstanding the MAUP, there are several reasons for choosing NUTS-3 regions as units of analysis. First, provinces are the intermediate level between municipalities and larger regions. Agglomeration economies may be relevant at several spatial scales. However, municipalities appear to be a too small level, given also the dynamics of territorial coalescence, according to which most of the urban areas are composed by more than one municipality. At the same time, regions (NUTS-2 level) may be too large for the exploitation of agglomeration benefits, also considering that Italian NUTS-2 regions are considerably larger than other European NUTS-2 level[4]. Hence, the provincial intermediate level appears to be the most suitable (administrative) level to minimise MAUP.

[4] With average population of 2.83 million inhabitants, Italian Regions are the largest NUTS-2 level regions in Europe (excluding Latvia, which has only one NUT-2 region) (Source: Eurostat).

Second, given the high degree of urbanization in Italy, core cities tend to be determined and path dependent. Provinces exist, with relatively minor changes, since the second half of 19th Century, and were based to the largest existing cities. So it appears reasonable that this spatial level has a still a strong role in the spatial organization of urban areas.

Third, provinces have relevant policy powers, especially in the field of territorial planning – a level which is intermediate between the regional level (that set up the general framework for land planning) and the municipal level. Hence, focusing on this spatial scale makes a perfect congruence between the object of analysis and the subject of policy. This then enables there to be a more direct and easy transposition of the results in terms of possible policy recommendations.

Fourth, the political and administrative powers of Italian NUTS-3 regions are provided for metropolitan areas.[5] The metropolitan area is the most investigated scale in the literature in terms of the regionalization of agglomeration economies.

Finally, data availability, for instance in productivity measurements (such as carried out in Chapter 3), means that the best unit of analysis is the NUTS-3 regions (Fiaschi et al., 2011). NUTS-3 regions have also been taken into account by many reports dealing on spatial development, including those carried out by the European Spatial Planning Observation Network (ESPON[6]), the Programme created by European Union to support territorial policy.

However, the concept of spatial structure is scalar, hence it can be applied to several territorial levels. Hence, the thesis provide an appendix to Chapter 2 that analyses NUTS-2 level polycentricity, since this is the most relevant spatial level to achieve the goals addressed by EU policies, such as ESDP and territorial agenda. After Chapter 3, an appendix considers whether the hypothesis of regionalization of agglomeration externalities holds for Functional Urban Regions (FURs) – assessing the role of polycentricity and urban dispersion for employment growth.

1.7 Methodology and plan of the thesis

In order to answer its main question, whether spatial structure can have a role for urban and regional development, the facts that have been sketched in this chapter show that there is no adequate empirical assessment. Spatial structure characteristics have gained quite a lot of success in territorial policies, as seen in the case of polycentricity – which has been turned in

[5] In 1990 Italian law introduced the possibility of setting metropolitan areas as units of analysis, which would take the same power as NUTS-3 regions. At the moment, no metropolitan area has yet been set.

[6] www.espon.eu.

‘polycentricism’. However, many of the policy propositions lack adequate analytical endorsement and empirical assessment. Some research points out the hypothesis of ‘regionalization’ of agglomeration economies and ‘borrowed size’, while other works have investigated the role of urban dispersion and sprawl. However, few works have been devoted to an integrated analysis of spatial structure.

A key problem, which hampered research on the economic effects of spatial structure, is represented by the complex and multidimensional nature of the concept, which conveys many aspects, definitions and measures. In order to answer the main research question, this thesis investigates the issue of the analytical definitions and measurements of spatial structure at the regional level. This is the topic of **Chapter 2**, which concentrates on two major aspects of spatial structure: polycentricity and dispersion. As highlighted in this introductory chapter, polycentric development and urban dispersion are subject to increasing interest. However, those aspects lack common and shared definitions and measures. This is especially true for polycentric development, which “remains a rather fuzzy concept as it seems to mean different things to different actors and on different scales” (Meijers, 2008, p. 1313). The chapter addresses the issue of the definition of polycentric development by reviewing the literature concerning the topics and identifying the main analytical dimensions involved, which are the morphological and the functional dimension. Then, it summarises and discusses the main measures that have been proposed by the literature. Compared to polycentricity, urban dispersion appears to have a more consolidated background about its definition and measurement. However it is a multi-faceted phenomenon as well. Hence, the chapter lists the main aspects of dispersion and possible measures. Some examples have been given to explain and discuss the measures used to measure polycentricity and dispersion.

An appendix to Chapter 2 applies some of the indicators proposed to the analysis of Italian NUTS-3 Regions, with particular reference to polycentricity. It shows the relationships between the morphological and functional dimensions and gives taxonomy accordingly. Then, it discusses the links between polycentricity and the policy goals stated by the ESDP and subsequent documents (as seen in sections 1.3 and 1.5): economic competitiveness, territorial cohesion and environmental sustainability.

Chapter 2 is preparatory to the subsequent empirical part of the thesis, which is presented in chapters 3 and 4. Both assess the role of spatial structure of Italian NUTS-3 Regions (*province*). **Chapter 3** analyses the role of spatial structure for territorial competitiveness of provinces. Following the most relevant literature in the field, competitiveness is conceptualised in terms of labour productivity. The chapter first states the rationale for the analysis and reviews the most relevant literature. Then it shows the results of the empirical work, which is based on regression analysis. Some methodological and empirical issues are also discussed. An appendix to chapter 3 has been added in order to show that other spatial scales than provinces can be taken into account when analysing the effects of spatial structure on economic development. The appendix considers Italian Functional Urban Regions

(FURs) as units of analysis – and to set a dynamic framework to assess economic competitiveness – which has been conceptualised in terms of population and employment growth.

Chapter 4 addresses the relationships between spatial structure and environmental pressure. It studies gas emissions from private road transport and house heating emissions. By surveying the most relevant literature it summarises the possible links between spatial structure and emissions. The survey provides the framework to explore the empirical evidence for Italian provinces concerning CO_2 and PMs emissions. A set of equations has been estimated by regression analysis, which considered separately transport and housing sectors.

Chapter 5 concludes, recalling the main results from the thesis, which allow for a critical discussion about the role of spatial structure, in particular polycentricity, on urban and regional development. It also discusses the drawbacks of the analysis and the lines of future research on the topic.

2 Defining and measuring spatial structure

Regional spatial structure has many dimensions, which involve several definitions and measures. This chapter tackles the problem of defining and measuring spatial structure under an integrated and multi-dimensional perspective. I adopt a taxonomy that distinguishes between two main aspects of spatial structure: polycentricity and dispersion. For each aspect, the issue of definition and measurement is discussed.

2.1 Spatial structure and the role of centres

Spatial structure is a multi-dimensional and complex phenomenon, which has been approached by several disciplines, such as geography, land planning, ecology, urban and regional economics.

According to Horton and Reynolds, the concept of spatial structure refers to "an abstract or generalized description of the distribution of phenomena in geographic space" (1971, p. 36). From an economic point of view, those phenomena refer to the economic activities of firms and households - namely residential and productive (or trade) activities - across space. The city is the environment in which those activities develop and influence each other. The main elements of spatial structures are "nodes" (e.g. plants, residences), linear features (e.g. transport networks) and surfaces (Horton and Reynolds, 1977, p. 36).

As highlighted in the literature (for instance by Lee, 2006, p. 9) urban spatial structure is the resultant of the distribution of people and economic activity across space, which is in turn the outcome of long-term processes involving locational preferences of agents and public policies. The distribution of economic activities, which is sometimes called "urban form" (Anderson et al., 1996), is related to urban interactions: urban form and interactions together give rise to spatial structure (Bourne, 1982).

The centres are the key elements in the regional structure and development. Being characterized by concentration of economic activity, the centres represent the economic core of spatial systems, providing functions to the rest of the region. Urbanization has promoted agglomeration economies (Glaeser et al., 1992) and cities represent the engines of economic growth for regions and countries. By means of several mechanisms, urban environments promote economic advantages for firms and households, which may turn into higher productivity, income and quality of life (Glaeser, 2011).

Actually, the dynamics of human settlements, both in history and space, can usefully be described by referring to the changing roles of the centres and of the territory around them. In some instances regions are organised around a main centre, in other we observed several interconnected centres, while the urbanization degree and patterns around centres may considerably differ (Camagni et al., 2002). Although we acknowledge the multi-faceted nature of the concept of spatial structure, this work focuses on urban dispersion and polycentricity (Meijers and Burger, 2010), two concepts that, despite their interrelationships (Gordon and Wong, 1985, 662), need to be kept distinct. In both cases, however, the centre is the fundamental concept that is used to define spatial structure.

2.1.1 The role of centres

The notion of centre represents the key notion of both aspects of monocentricity/polycentricity and centralization/dispersion.

Centres represent areas characterised a certain level of agglomeration and density of economic activity, which provide functions for a spatial scope that exceeds their areas. When the spatial area to be considered is a region, centres can be conceptualised by cities. If the spatial area taken into account is a city, the centre has been conceptualised by its Central Business District (CBD) that is the main economic core of the city.

The notion of centres as basic concepts to define hierarchies within regions was firstly introduced in geography by the seminal contribution of the German geographer Walter Christaller (1893-1969). In this famous contribution (1933) Christaller developed a theory to explain how economic activities[7] organise over space, generating urban hierarchies. Accordingly, central places maximise the matching between supply and demand of services. Services provided by centres do differ in terms of their thresholds, which are the minimum market needed for a certain service or good to be sold (e.g. to benefit from agglomeration economies), and ranges, which are the maximum distance that consumers are willing to travel to buy goods and services. Differences in thresholds and ranges describe hierarchies of functions: high-quality services are characterised by higher threshold and ranges, hence are concentrated (Jacobs, 1969). The highest function defines market areas. Then, lower functions

[7] In particular, Christaller considered trade services.

locate where the highest functions are already localised. Since lower functions have lower ranges, their market areas are smaller than higher functions: this causes that some areas of the regions are not covered by the function. This allows for the existence of sub-centres, which provide functions, except for the highest.

As a result, settlements within a region are characterised by a hierarchy: the main centre, which is the regional capital, hosts all possible functions (in terms of provision of services and goods), other centres are characterised by the supply of lower-level functions and ranked according to the number of function they host: cities, towns, market towns, villages. Three kinds of forces determine the spatial organization of the regional economy: the market principle (i.e. the minimization of centres providing the highest function), the transport principle (i.e. the minimization of transport costs for the provision of high level functions), and the administrative principle (i.e. the allocation of lower centres to only one upper centre). Those principles determine factors of proportionality with reference to the number of sub-centres. According to the market principles, there are three lower-order centres for each higher level area. According to the transport principle, there are four lower-order centres for each higher level area. According to the administrative principle, there are seven lower-order centres for each higher level area.

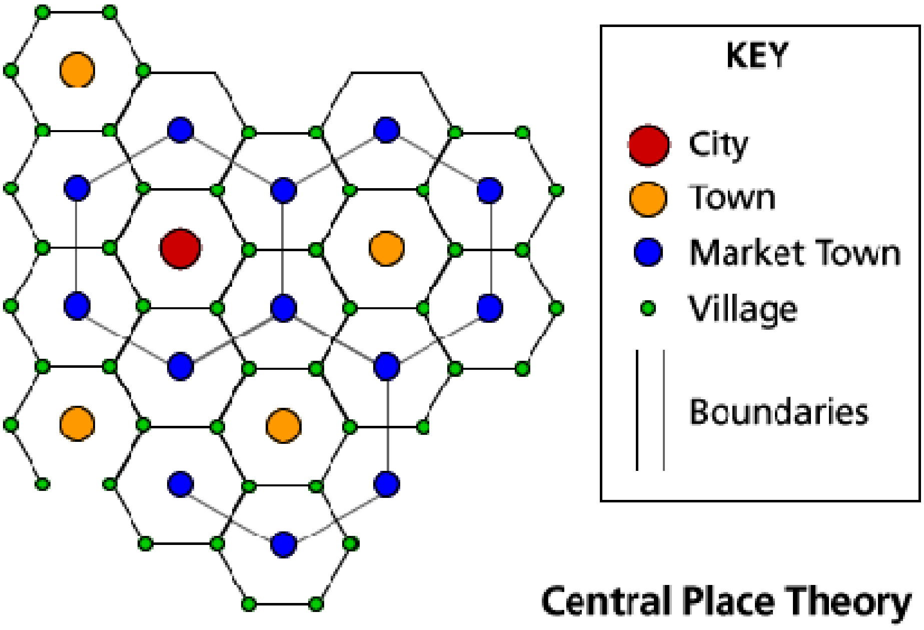


Figure 2.1: Christaller regional hierarchy of centres
(Source: http://www.wolfatthedoor.org.uk/mainpages/sustainability.html)

The approach of Christaller was then reprised and developed by August Lösch (1906-1945). In 1940 he developed a model that criticised some of the rigidities of Christaller's theory, such as the fixed factors of proportionality. Lösch's model also allows for centre specialization: a high level centre may not host lower order functions: centres of comparable size may differ in terms of functional specialization (Camagni, 1992).

However, both approaches conclude that regions are organized according to hierarchies, and those hierarchies are defined by the functions provided by centres. Economic factors, such as transport costs, competition between firms, consumer rationality, minimization of administrative costs, drive the spatial organization of regions, in terms of number of centres, their functions and their localization (in terms of distances between centres). The works by Christaller and Lösch, which represent spatial equilibrium models, stimulated a branch of literature aimed to assess regional spatial organization (Beckmann and Pherson, 1970; Beguin, 1984; Parr, 1985; Mulligan, 1984; Nijkamp, 1986).

2.1.2 The role of spatial interaction and networks of centres

The system of linkages between centres, and between centres and their surroundings, represent the second key concept in the definition of spatial structure. It has been shown how those relationships are increasingly important in urban development. In fact, in many cases urban growth patterns have been in contrast with the predictions made by Central Place Theory (Camagni, 1993). Sometimes centres have shown urban specialization (hence contrasting Christaller theoretical predictions). In other cases large centres do not show the presence of all functions, while smaller centres host high-rank functions. Centres can be linked to other centres specialised in similar functions (e.g. financial services, ICT) and located beyond the region, while within the region synergies among similar centres may happen (e.g. industrial districts) (Capello, 2007).

Networks are involved in many of the above-mentioned facts. Hence, a theory of city networks developed in order to interpret structure and evolution of urban systems. Accordingly, relations between centres can be not only hierarchical, but also horizontal, that is between cities of comparable rank.[8] As result, networks of complementarity or networks of synergy can characterise urban regions. Complementarity networks are characterised by economic specialization of each centre, while synergy networks consist in linkages between similar centres that are likely to cooperate. In the latter case, centres benefit from network externalities (Camagni and Salone, 1993). A particular case of synergy networks is represented by the innovation networks, where centres cooperate in order to reach the scale economies needed to carry on innovative activities (e.g. infrastructures) (Capello, 2007).

[8] "City networks consist of sets of horizontal, not hierarchical, relationships among complementary or similar centres. These relationships generate economies or externalities of, respectively, specialization/division of labour and of synergy/cooperation/innovation" (Capello, 2007, p. 80).

2.2 Polycentricity

At first glance, polycentricity can be defined as the presence of more than one centre in a circumscribed spatial system. However, it is a complex and fuzzy concept, which has been tackled by different perspectives, adopting different definitions and measures. Additionally, it may be applied to several spatial scales.

Actually, there are two main approaches to polycentricity: the morphological approach and the functional approach. Probably, the most important difference between the functional and the morphological approaches to polycentricity consists in the concept of "centre", which is at the origin of the notion of polycentricity. Morphologically, an urban centre could be simply defined as an agglomeration of jobs and people. In the literature aimed at identifying sub-centres, an agglomeration is considered to be a centre if it exceeds certain thresholds of absolute population (or jobs) and employment density[9] (Giuliano and Small, 1991). On the other hand, from a functional perspective, an urban centre is a place that wields power in the territory around it. As seen above, according to Christaller, a centre can be considered a place that supplies central functions to its surrounding territory. Thus the concept of a centre is very similar to a 'central place'. Hence, a region could be viewed of as functionally polycentric if it is organised around two or more centres or focal points, places that supply central functions to the whole region or – at least – to a portion of it.

Notwithstanding the differences between the concepts of polycentricity from the two perspectives, it is reasonable to think that functional and morphological indicators of polycentricity could – at least to some extent – be positively correlated. This is because, despite the different basic concepts of 'centre', both approaches investigate the same phenomenon, which is to measure the degree to which a region is characterised by the coexistence of several centres, instead of being organised around a single core.

2.2.1 Spatial scales involved in polycentricity

The lack of empirical evidence on the effects polycentric development may be due to its multi-scalar nature. In fact, polycentricity can refer to at least three spatial scales: intra-urban, inter-urban and interregional (Davoudi, 2003). The intra-urban scale was originally used by scholars for the notion of polycentricity to conceptualise the distribution of economic activities across space. Already in the 1920s, the Chicago School sociologists and land economists considered the possibility that new sub-centres could emerge near central business district, forming a polycentric urban structure (Harris and Ullman, 1945). Since the 1970s, bid-rent theory models

[9] Other more complex approaches look at density peaks, hence focusing on those territorial units that show higher densities than areas in the surrounding territory. See, among others, Craig and Ng, (2001). For a recent survey on this topic, see Roca Cladera et al. (2009).

have been developed, based on a polycentric spatial structure (White, 1999; Glaeser and Kahn, 2004).[10] Hence, polycentricity has probably been investigated the most in terms of the intra-urban scale, both in relation to its drivers and its effects.

Polycentricity has also been referred to at the inter-regional or inter-national scale. (Waterhout et al., 2005). Several metaphors in the scientific debate relate to polycentricity at this level, such as the 'Megalopolis' or the 'Mega-city-region' (Gottmann, 1961), the 'urban field' (Friedman and Miller, 1965) or the 'poly-nucleated urban field' (Dieleman and Faludi, 1998, p. 374). However, the notion of spatial interdependency among urban nodes has neither been defined, or sufficiently rigorously investigated (Van Houtum and Lagendijk, 2001, p. 748). Other even more visionary metaphors include the 'Blue Banana' (Brunet, 1989), the 'Golden Triangle' (Cheshire and Hay, 1989) and the 'Pentagon' (CSD, 1999). The Pentagon was used by European Union in the ESPD to identify a rich transnational polycentric region that includes Paris, Milan, Hamburg, Munich and London metropolitan areas.

Lastly, polycentricity can refer to the regional or inter-urban scale. This concerns administratively defined regions or city-regions (if approaching functionally defined spaces). The latter are organized around several cities or urban areas. Unlike the intra-urban scale, these cities should be separated from each another. More precisely, an area can be called a Polycentric Urban Region if a set of conditions is fully satisfied in terms of centre separation, distribution, specialisation and interaction among centres (Parr, 2004, p. 232). The inter-urban scale is the spatial level issued by this thesis.

2.2.2 Morphological and functional polycentricity

As pointed out in Chapter 1, polycentric regional structures and their economic development have been subject to increasing interest and research. However, 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, and institutional) and several 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

[10] Glaeser and Kahn (2004), for instance, study the emergence of sub-centres in US urban areas, driven by income and private transportation use.

of economic advantages arising in cities.[11] Then, cumulative causation processes determine higher growth and consequently more incentives 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 across 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.

Focusing on the regional level, some authors outlined the main features of polycentric regions, both from the morphological and the functional approach. Kloosterman and Musterd (2001, p. 628) listed the main characteristics of a polycentric region as follows:

- A number of historically distinct cities;
- No clear leading city, which dominates in political, economic, cultural and other aspects;
- A small number of large cities that do not differ that much in terms of size or overall economic importance, together with a greater number of smaller cities;
- Cities are located in more or less close proximity (mainly within maximum commuting distance);
- Constituent cities are spatially and politically distinct from one another.

Later on, John Parr developed a similar framework, listing the aspects involved in the definition of polycentricity at regional level, which can be listed as follows (Parr, 2004):

1) Clustering of separate centres, with lower and upper limits on centre separation;
2) Size and spacing of centres;
3) Size-Distribution of centres
4) Centre specialization;
5) Interaction between centres.

Points 1-3 refer to the morphological dimension, while points 4-5 are aspects of the functional dimension.

Point 1 means that a polycentric region is composed by urban centres which are spatially clustered. Hence, their spatial distribution differs from regular or random distribution. The centres 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

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

to the same region should be in the range:

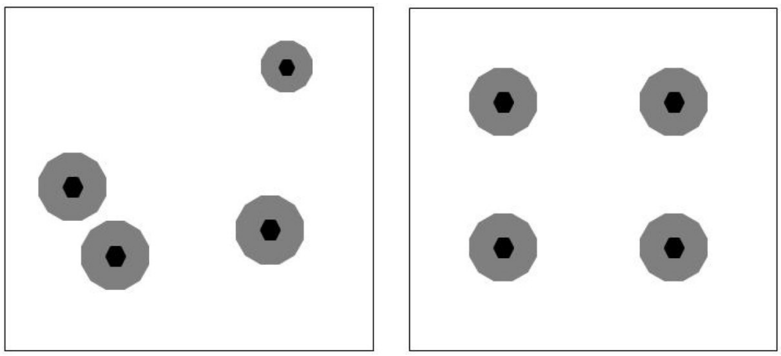
$$d_{ij(min)} < d_{ij} < d_{ij(max)} \qquad (1)$$

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 distance or in travel time. The value of $d_{ij(min)}$ represents the open space between centres, thus $d_{ij} > 0$ allows distinguishing polycentric regions from regions where coalesced/sprawled cities or conurbations prevail. Hence, $d_{ij(min)}$ is often expressed in terms of Euclidean distance, rather than time. The upper bound $d_{ij(max)}$ is a defined threshold that allows circumscribing the region: it might be, for instance, the distance covered by a car trip of one hour (Bailey and Turok, 2001; Green, 2007). In this case d_{ij} is defined as the distance between the two centres that are farthest apart within the region. The one-hour travel is a threshold used also to define Daily Urban Systems, which are the areas around cities where daily commuting occurs. Alternatively, $d_{ij(max)}$ could be computed as follows:

$$d_{ij(max)} = D + \sigma_t \qquad (2)$$

where D is the average distance between the centres and σ_t is the standard deviation of all distances between the cities belonging to the region (Green, 2007).

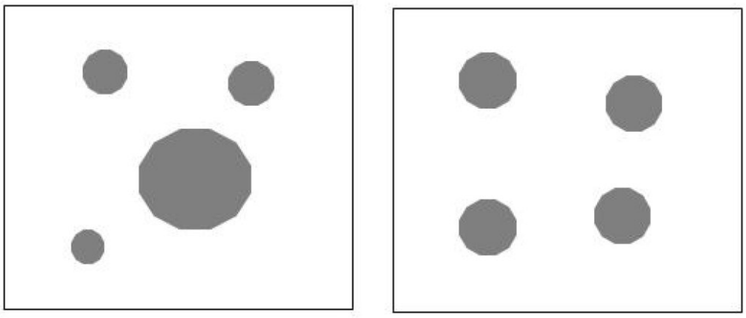
Point 2), size and spacing of cities, means that the spacing of cities across the region should be balanced: cities in an ideal polycentric region should have the same (physical or time) distance from each other.



(a) *Unbalanced region.* (b) *Balanced region.*

Figure 2.2: Spacing of cities

The size-distribution (point 3) refers to the physical hierarchies in regions. According to this aspect, regions can be distinguished in mono-nuclear or 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. In a polycentric region centres the centres must not be too dissimilar in terms of size, since there may not be any evidence of primacy at the top of the population distribution (Hall, 2009, 261). Hence, the hierarchical ranking of cities is usually assessed by looking at the size-distribution of cities (Beckmann, 1958).



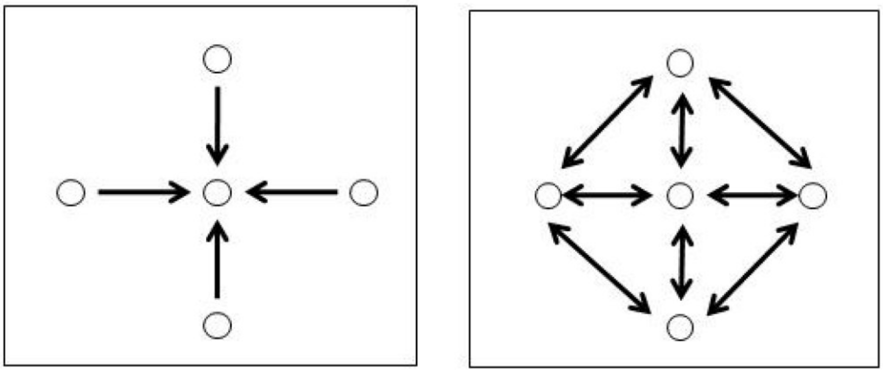
(a) *Hierarchical (Mono-nuclear) region.* (b) *Non hierarchical (Poly-nuclear) region.*

Figure 2.3: Size-distribution

Specialization of centres (point 4) 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 result, cities become interdependent to each other. So, polycentric regions can promote 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 (Rosenthal and Strange, 2004). 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 – especially the Randstad, i.e. the region composed by the four largest Dutch cities (Amsterdam, Rotterdam, The Hague and Utrecht) and their surroundings – represents 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 the Randstad has been often referred as an archetypal polycentric structure.

The other functional aspect is the interaction among centres (point 5). Cities are physically interconnected by infrastructures and by flows (e.g., flow 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 interdependencies form important hubs and links" (Commission of the European Union, 1999, p. 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 centres 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) *Monodirectional relationships.* (b) *Multidirectional relationships.*

Figure 2.4: Relational dimension

To sum up, in both the morphological and the functional approach, a polycentric region is supposed to be characterised by the coexistence of more than one urban centre (Riguelle et al., 2007, p. 195). However, there are several points where the two approaches differ substantially. First, morphological polycentricity focuses on the fact that centres must be clearly physically separated. At the same time, centres must not be too far from each other, since there must be an interaction and a minimum proximity that allows the region to be considered as a single territorial entity.

Second, from a morphological perspective, centres must not be too dissimilar in terms of size, since there may not be any evidence of primacy at the top of the population distribution (Hall, 2009, p. 261). On the other hand, from a functional perspective, the focus is on the distribution of functions and, as a consequence, on the centralities emerging within the region from the interaction among urban centres. The hierarchical ranking between cities is assessed using interaction measures, often based on the flow of people, goods or information, by making use of tools borrowed from network analysis.

These distinctions enable to highlight what is probably the most important difference between the functional and the morphological approaches to polycentricity. This difference is in the concept of 'centre', which is at the origin of the notion of polycentricity. Morphologically, an urban centre could be simply defined as an agglomeration of jobs and people. In the literature aimed at identifying sub-centres, an agglomeration is considered to be a centre if it exceeds certain thresholds of absolute population (or jobs) and employment density[12] (Giuliano and Small, 1991). On the other hand, from a functional perspective, an urban centre is a place that wields power in the territory around it. As seen in the previous section, according to Christaller, a centre can be considered a place that supplies central functions to its surrounding territory. Thus the concept of a centre is very similar to a 'central place'. Hence, a region could be viewed of as functionally polycentric if it is organised around two or more centres or focal points, places that supply central functions to the whole region or – at least – to a portion of it.

Notwithstanding the differences between the concepts of polycentricity from the two perspectives, it is reasonable to think that functional and morphological indicators of polycentricity could – at least to some extent – be positively correlated. This is because, despite the different basic concepts of 'centre', both approaches investigate the same phenomenon, which is to measure the degree to which a region is characterised by the coexistence of several centres, instead of being organised around a single core.

2.2.3 The measurement of morphological polycentricity

There are several methods to measure the degree of morphological polycentricity. The first is to consider the ratio of people living in the main city over the total population in a region (*primacy*), as shown in equation 3, where *n*=1 indicates the main city:

$$Primacy = \frac{population\ (1)}{\sum_{n=1}^{N} population\ (n)} \tag{3}$$

This simple indicator can be applied to describe the dominance of the prime city in relation to the region: the higher the primacy, the more monocentric the region. However, it contains no information on the size distribution of all other cities, which may both be very equal or unequal. Actually, as discussed 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 regularity in the size-distribution of population, as result of the mechanisms that lead to the growth of cities. These regularities hold at several spatial scales. One of the most popular empirical regularities is the Zipf's Law for cities, according to which the distribution of city-size can be approximated by a power law

[12] Other more complex approaches look at density peaks, hence focusing on those territorial units that show higher densities than areas in the surrounding territory. See, among others, Craig and Ng (2001). For a recent survey on this topic, see Roca Cladera et al. (2009).

distribution, or Pareto distribution[13] (Gabaix, 1999; Gabaix and Ioannides, 2004). In other words, the probability to find a city having size is greater than S is inversely proportional to S. The form is:

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

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

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

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 we obtain:

$$\frac{a}{S^{\beta}} = \frac{R}{N} \Rightarrow \ aN = RS^{\beta} \ \Rightarrow \ R = \frac{aN}{S^{\beta}} \tag{6}$$

The Rank-Size rule is an approximation used in order to visualize 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):

$$\ln(Rank) = \ \alpha \ + \beta \ln(Population) \tag{7}$$

where the coefficient β is by construction negative. The case known as the Rank-Size rule holds if the value of β is −1 (Gabaix and Ioannides, 2004, p. 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) and other countries.[16] However, some other studies refute the

[13] Auerbach (1913) already demonstrated that city-size distribution might be approximated by a Pareto distribution.

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

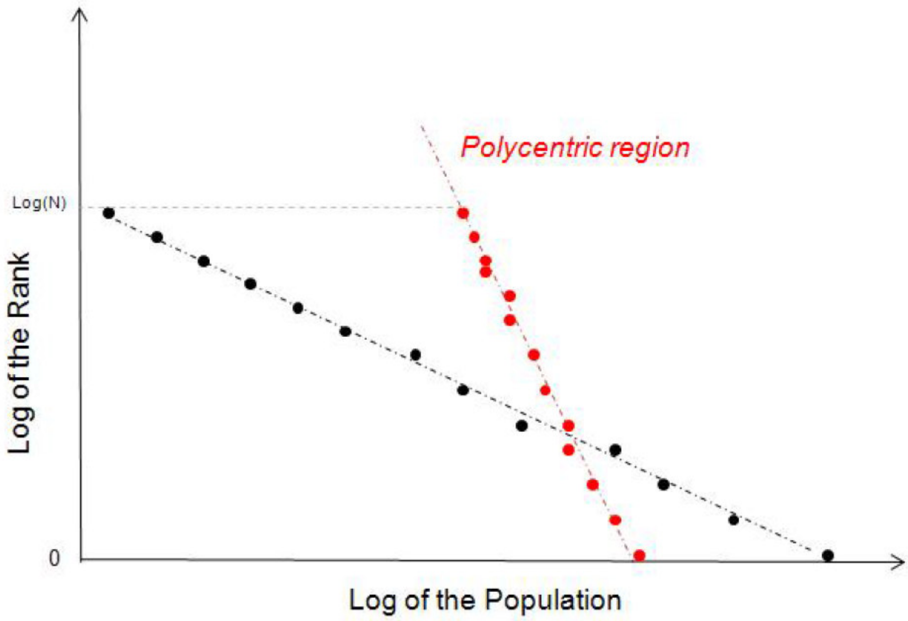
[15] Of course α must be equal to ln(Population) of the largest city, in order to have rank=1.

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

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. In particular, when small towns are included in the analysis, the city-size distribution ceases to be approximated by a Pareto distribution, but it has been shown to be lognormal (Eeckhout, 2004). Hence, the value of the estimated β is highly sensitive to the number of cities taken into account to assess the regional hierarchy. 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) (Gabaix and Ioannides, 2004).[17] 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. 50000 inhabitants, or 20000 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). Some studies (see, e.g., Meijers and Burger, 2010; Burger and Meijers, 2012), consider just the largest three or four centres within the region.

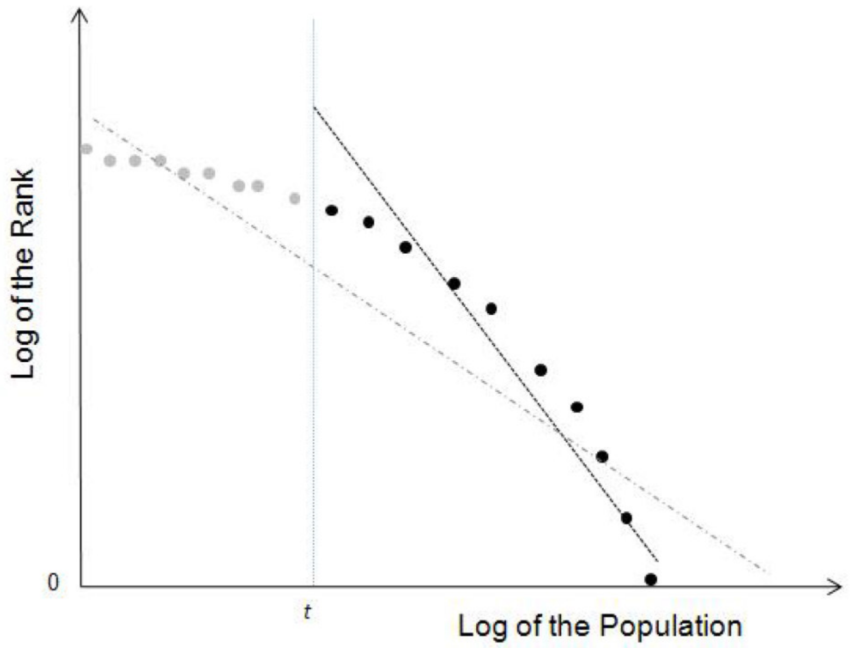
It is important to remark that the issue of the thresholds is related with the functional form used: by using OLS one might estimate with high precision the distribution of biggest cities – that generally are log-linearly distributed – while the estimation would be less accurate by taking into account the entire sample.



(a) *Rank-Size estimation for two different regions.*

[17] This especially holds for small samples.

Figure 2.5: Rank size log linear estimations



(b) *Example of threshold, non linear relationship.*

Figure 2.6: Effects of threshold in a non linear rank-size relationship

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 rank size equation can also be expressed in the so called "Lotka form" (Parr, 1985):

$$\ln(Rank) = \alpha + \beta \ln(Population) \tag{8}$$

In this case, the lower the absolute value of the estimated β, the higher the polycentricity. In the following chapters, the choice of the dependent variable of the rank size estimation will be based on the relevant literature in the topic.

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. In general, the estimation of the rank-size distribution for city-size distribution fit the data well (Brakman et al., 1999)

Moreover, by comparing data over time, it is possible to get information about the evolution of urban systems: increasing (absolute) 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, p. 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 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.

2.2.4 The measurement of functional polycentricity

As discussed 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 used 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, p. 48), but also other types of flows can be studied. Camagni and Salone (1993), for instance, propose to use the total amount of communications and information flows going out of and into each centre.

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 between cities.

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 often unclear (Sohn, 2005).

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.

2.2.4.1 Green Indexes of polycentricity

Among others, Green developed a set of indexes aimed to measure the degree of functional polycentricity. The work of Green was grounded in the analysis of networks, which comprises *actors* and *linkages* between actors. In the case of polycentricity, the actors are represented by urban centres. First, the author fixed two rules for the existence of functional polycentricity:

1. The space must contain more than one node;
2. The nodes must be linked to one another.

In a network, the more evenly distributed the linkages the higher the level of polycentricity.

By defining a network composed by a set of nodes

$$N_F = \{n_1, n_2, \dots\ n_g\} \tag{9}$$

With set of linkages

$$L = \{l_1, l_2, \dots\ l_g\} \tag{10}$$

The level of polycentricity can be obtained by analyse the distribution of linkages. This is done by analysing the nodal degree, which is the number of links that each centre has with the others. More specifically, Green proposed to compute the actual standard deviation of the nodal degree of the network to a notional maximum standard deviation:

$$OP = 1 - {}^{\sigma_F}/_{\sigma_{F\,max}} \tag{11}$$

where σ is the standard deviation of the nodal degree (*nd*) within the region, σ_{Fmax} is the standard deviation of the nodal degree of a fictitious 2-nodes network where $nd_1 = 0$ and nd_2 is the highest nodal degree in the actual network. *OP* ranges from 0 to 1, where 0 indicates perfect monocentricity (i.e., centres are not linked to each other) and 1 perfect polycentricity.

OP Index, however, does not satisfy condition 2: in fact, the index could hypothetically be the same for a totally connected network, in which all nodes are linked to each other, and an unconnected network. In order to overcome this issue, Green applied the notion of *network density*, which can be defined as follows (Wasserman and Faust, 1997):

$$\Delta = \frac{L}{L_{max}} \tag{12}$$

Where L is the actual number of edges in the system and L_{max} is the maximum possible value of all edges in the graph. When taking into account commuting data, for instance, L is the total value of commuters (from one centre to another), and L_{max} the potential value of commuters. There are many ways to compute L_{max}. Green proposed to compute L_{max} as the sum of all potential commuters to the node with the smallest population.

From OP index and network density the Special Functional Polycentricity index is obtained as follows:

$$P_{SF} = (1 - \frac{\sigma}{\sigma_{max}})\Delta \tag{13}$$

As the OP index, P_{SF} ranges from 0 to 1, where 0 indicates perfect monocentricity and 1 perfect polycentricity. Potentially, all type of flows between centres can be used in the index; actually, data availability makes figures about commuters the most commonly used.

P_{SF} is based on a definition of functional polycentricity which is essentially based on three features. First, since polycentricity is defined as a network theoretic function, it does not consider physical distances between nodes, i.e. urban centres. This allows the index to be applied to many spatial scales. Second the definition of the P_{SF} index takes into account network density: this means that it considers the level of interaction within the network. In other words, it takes into account “the extent to which a network of places may be considered to be a single system” (Green, 2007, p. 2086). The density of interaction distinguishes polycentric areas from other spatial organization typologies. Third, the second component of the P_{SF} index, the OP index, means that in a polycentric network the flows should have an even distribution over the centres, rather than being directed towards a single node.

A further step tackled by Green is to summarize several functional flows within a network (e.g. commuting, leisure trips, trade flows …), which result in several values of the Special Functional Polycentricity, getting the General Functional Polycentricity Index:

$$P_{GF}(N_1, N_2, \dots N_n) = \frac{\sum_n P_{SF}(N_1, N_2, \dots N_n)}{n} \tag{14}$$

where $N_1, N_2, \dots N_n$ are the networks defined by each function n taken into account. Φ represents a "complementary modifier" that considers the balance of each functional network relative to the others. In other words, the complementary modifier takes into account the possibility that, in a region, centres may specialize in a single function and thus be complementary: in this case, when investigating polycentricity for a single function, the region is considered monocentric, while it is considered polycentric when the whole set of functions is taken into account. Actually, Φ is computed as the standard deviation of the values of Ordinary Polycentricity for the functional networks in the region.

2.2.4.2 The "S-dimension" approach

An alternative approach to functional polycentricity has been proposed by Limtanakool et al. (2007, 2009), which developed a set of indicators, referring both to the entire regional systems and the single centres and the links– in order to describe the "S-dimensions": structure, strength and symmetry of spatial systems.

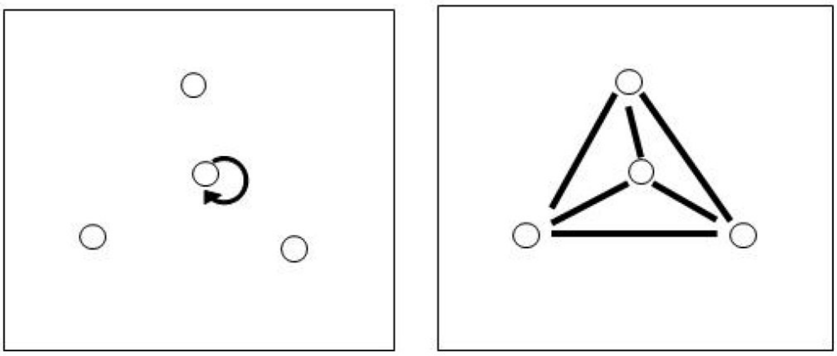
Structure The Entropy Index (EI) is a synthetic indicator of the structure in the entire regional system. It has been defined as follows by Limtanakool et al. (2009):

$$EI = -\sum_{1}^{L} \frac{(Z_i)\ln(Z_i)}{\ln(L)} \tag{15}$$

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. By definition, for $Z_i = 0$ holds that $(Z_i)\ln(Z_i) = 0$.

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.

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 9a), while a value 1 reflects a fully polycentric system (Limtanakool et al., 2009, p. 183) in which all centres are involved in the interaction, with equal intensity.



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

Figure 2.7: 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. The former considers only the exits from each centre, while the latter takes into account the entries.[18]

The comparison between these two indexes – with reference to the same regional system – would allow taking 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 to be polycentric in the residential structure. In general one might expect the EI for in-commuting lower compared to the EI for out-commuting, since the residential activity is more spread than the spatial job markets. Thus, the higher the difference between the indexes the higher is 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):

$$EI_i = -\sum_{j=1}^{J} \frac{(x_j)\ln(x_j)}{\ln(J-1)} \tag{16}$$

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 w.r.t. a node have the same value) for every node.

[18] 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.

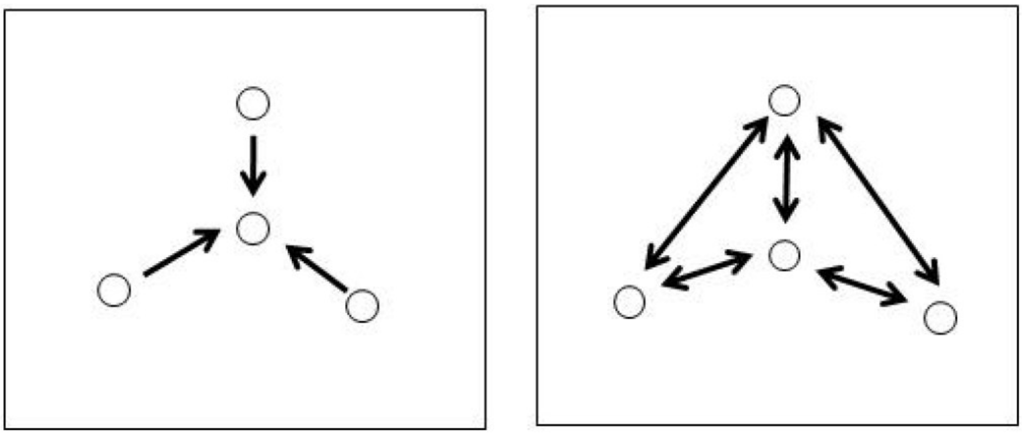
Strength This dimension concerns the intensity of interaction between nodes. By taking into account this aspect, one might see, in a region, what are the centres involving the higher intensity of interaction, measured in terms of attraction of flows from other cities.

A first indicator of 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 relative to the total commuting of a region:

$$DI_i = \frac{I_i}{\sum_{j=1}^{J} I_j / J} \tag{17}$$

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. Ij 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, relative to the average degree of "attractiveness" of the region. 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= 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, 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 (Figure 2.8). 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 2.8: Dominance index

The strength 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 Strength Index (RSI_{ij}), which is defined at the link level, as follows Limtanakool et al. (2009):

$$RSI_{ij} = \frac{T_{ij}}{\sum_{i=1}^{I}\sum_{j=1}^{J} T_{ij}} * 100 \tag{18}$$

where T_{ij} represents the flow from node i to node j. The RSI_{ij} ranges 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:

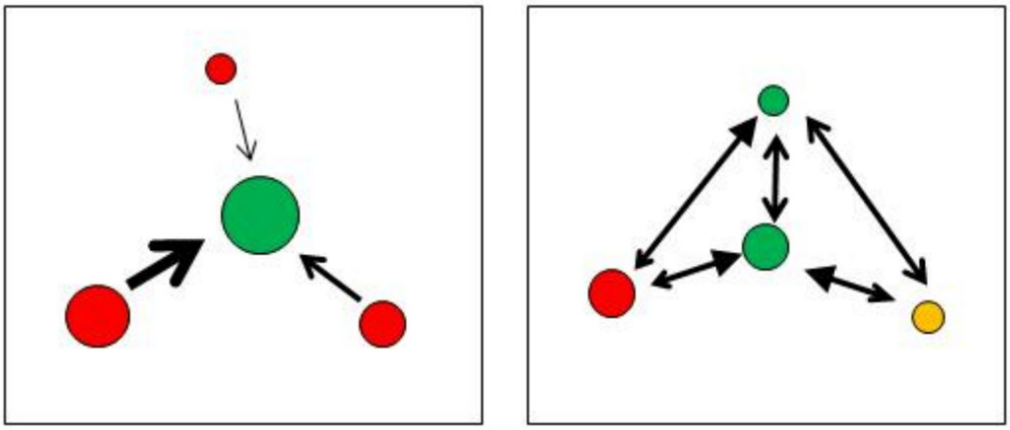
$$B_i = I_i - O_i \tag{19}$$

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):

$$NSI_i = \frac{I_i - O_i}{I_i + O_i} \quad (20)$$

where $O_i$is the number of journeys originating from node i.[19] 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_i. 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 2.9 (a) the central node has NSI_i = 1, while NSI_i would be —1 for all other nodes. The average value and the 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 2.9: Node-symmetry index

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

$$LSI_{ij} = \frac{f_{ij} - f_{ji}}{f_{ij} + f_{ji}} \quad (21)$$

where f_{ij} is the amount of flows on the link from node *i* to node *j* and $f_{f_{ij}}$ 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.

[19] The 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).

2.3 Urban dispersion

Urban dispersion refers to the extent to which economic activities are spatially concentrated in centres or, conversely, evenly dispersed. Hypothetically, we have two polar cases depending on where most of human activity is settled, either concentrated in one (or more) centre or diffused uniformly across the region. Recent dynamics in rich countries has often moved regional structure towards dispersion rather than concentration, generating the so-called "urban sprawl" (Figure 2.10).

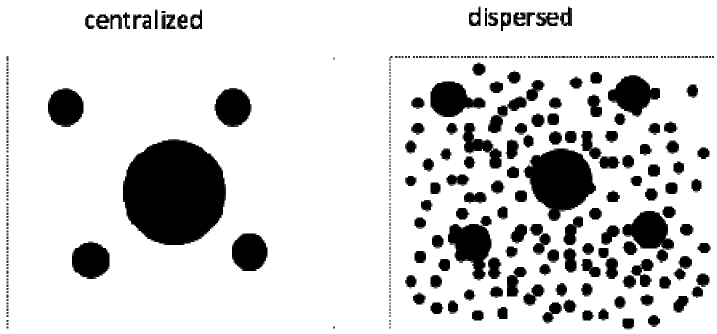


Figure 2.10: Centralized and dispersed regions

During human history, regions have been characterized by concentration of economic activities. Transport costs, both for goods and people, strictly bounded location choices, and represented the main driver for the concentration of activities in centres. Workers needed to live in proximity of their workplaces, and both residences and plants were located within city boundaries. The Industrial Revolution in the late 18th century was characterised by many innovations in the field of transport, which started to affect location choices. Those were mainly made from firms, because the new form of productive sites, the factories, required changes in their organization, involving proximity to inputs and energy, as well to markets. Still cities continued to be concentrated.

Innovation in mass transit, in particular with the introduction of the steam street-car, which appeared in North America in the second half of the 19th century, and was followed by the invention of the electric streetcar, allowed people to live further away from their workplaces, but it did not affect dramatically urban dispersion. The increase in urban dispersion became relevant in North America in the first half of 20th century due to the revolution involved by mass motorization (Burchfield et al., 1998). Commuting became cheaper and easier allowing more freedom in the choice of the residential location. People did not anymore need to live close to their workplace or commercial activities and started to relocate out from city cores. Residential relocation firstly involved upper income classes, who initially could afford the use of private vehicles, then, due to the decline in transport costs, also low income households attracted by the cheaper land prices of the surroundings (Le Roy and

Sonstelie, 1983). The cheap land prices also made the new settlements to be characterized by extensive land use. Similar dynamics appeared later on in Europe and other areas, where urban growth came together with urban sprawl in the last decades, in particular in the most advanced regions and in areas characterized by rapid economic growth (European Environment Agency - EEA, 2006). Urban dispersion is characterised often by patterns of single use zoning, low density zoning, car-dependence and spatial mismatch (Camagni, 2002b).

2.3.1 Definitions of dispersion

A comprehensive understanding of urban dispersion requires acknowledging its multidimensionality, involving several interconnected aspects and driving forces such as economic development, technological progress, change in preferences, regulatory framework, geography and climate, and others (EEA, 2006, p. 17). Actually, urban sprawl has been approached by different disciplines and points of view (Frenkel and Ashkenazi, 2008; Arribas-Bel et al., 2010) resulting in a large amount of literature. As a consequence, there is no widely accepted definition and measure for it (Galster et al., 2001; Chin, 2002). However, the commonly shared idea is that urban sprawl relates to patterns of excessive geographical expansion of urban settlements. The Random House Learner's Dictionary of American English, defines urban sprawl as "the uncontrolled spread of a city into outlying regions". The Merriam Webster Dictionary defines urban sprawl as "the spreading of urban developments (as houses and shopping centres) on undeveloped land near a city". This involves a sub-optimal utilisation of land (Brueckner, 2000). In static terms, this means that the distribution of economic activities across space is mainly characterized by extensive land use.

Among others, one of the most comprehensive definitions of urban dispersion is provided by the contribution by Galster et al. (2001), which tackles the multidimensionality involved in the concept of urban dispersion. They consider dispersion as composed by the following eight dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, proximity.

1. Density

Density and in particular residential density, is the mostly approached dimension on urban sprawl.

2. Continuity

Continuity is "the degree to which developable land has been built upon at urban densities in an unbroken fashion". The relationship between continuity and dispersion is controversial. According to Ewing (1997), urban sprawl is characterised by continuity: a dispersed urban area presents continuous low-density development. However, it may happen that dispersion is characterised by discontinuity. This is the so-called "leapfrog development", which happens when new urbanised areas are built at some distance from pre-existing urbanised land. Hence, according to Galster et al. (2001, p. 689), “sprawl can be continuous in some places and discontinuous in others “.

3. Concentration

According to Galster et al. (2001, 691) concentration “is the degree to which development is located disproportionately in relatively few square miles of the total urban area rather than spread evenly throughout”. So, it can be approached looking at the distribution of residential density across urban areas. Lower concentration might be related to urban dispersion.

4. Clustering

Clustering indicates “the degree to which development has been tightly bunched to minimize the amount of land in each square mile of developable land occupied by residential or non-residential uses” (Galster et al., 2001). Hence, this dimension relates to the patterns of development within urbanized land parcels. Low clustering may be related to low density and sprawled development.

5. Centrality

The centrality reflects “the degree to which residential or non-residential development is located close to the central business district of an urban area” (Galster et al., 2001, 694). Dispersed regions are assumed to be characterised by loss of centrality, because a larger share of population or economic activity relocates from centre, or centres, to their outskirts.

6. Nuclearity

Nuclearity relates to the number of centres within urban areas. Hence, it is related to the concept of polycentricity. As noticed by Galster et al. (2001), nuclearity and concentration are not necessarily related. Galster et al. infer that polynuclearity, that is polycentricity, can be opposite to urban sprawl.

7. Mixed uses

This aspect reflects the “degree to which different land uses commonly exist within the same area. Dispersed urban areas are often characterised by homogeneity in the type of land uses between parcels of urban areas: in other words, a dispersed area is characterised by separation of different kinds of land uses, so that, for instance, commercial activities are far away from residential dwellings. Hence, the lack of “functional mixité” may be an important indicator for urban sprawl.

8. Proximity

Proximity indicates the degree to which a land use is located close to the same land use across an urban area.

2.3.2 The measurement of dispersion

Notwithstanding the multidimensionality of urban sprawl, most of the literature approaches urban sprawl by focusing on gross residential density, that is, the number of residents (or residential units) per unit of land (e.g. Travisi et al., 2010). This, however, does not allow for comparability across regions with different geographic features and planning policies. For this reason, as suggested among others by Galster et al. (2001), net density is a better indicator, which is, density calculated with respect to the land that can be used, and the so-called developable land.[20] We may proxy developable land with land actually used for artificial purposes as provided by remote-sensing data (Burchfield et al., 2006).

Net density represents a straightforward indicator for urban sprawl, since it measures the intensity of the actual use of built land. Its main advantage as compared to gross density is that it allows comparability among regions with different geographic features and planning policies.

The economic literature has mainly used density as indicator for urban sprawl. However, some authors also developed other indicators. Some of them tend to overlap with indicators of monocentricity and polycentricity. For instance, a first index is the ration between the jobs located in the main centre[21] and the total regional employment (*PJ*):

$$PJ = e_{CBD}/E \tag{22}$$

where e_{CBD} is the employment within the Central Business District, which can be the central municipality within a region, and E is the total employment of the urban region. *PJ* represents a basic and straightforward measure for centralization (dispersion), providing information about the role of the main centre in terms of employment. The higher the value, the higher is the centralization of the region. Its implicit assumption is the monocentricity of the urban region, which is characterised by the existence of one centre (the central business district).

A more refined index for dispersion is the weighted average distance from the CBD, or ADC indicator. This index derives from a centrality indicator proposed by Galster et al (2001, p. 701), and it is computed as follows:

[20]"Land that has no natural features, public uses, or regulatory barriers to its development at urban densities—is a better denominator for calculating density than total land area. It is also a more useful area for measuring all the other dimensions of land use patterns" (Galster et al., 2001, 688).

[21] By main centre or pivot centre we refer to the largest municipality in terms of population.

$$ADC = \sum_{i=1}^{n} \left({}^{e_i}/_{E} \right) * DCBD_i \tag{23}$$

where e_i is the number of jobs in the *i*-th municipality and $DCBD_i$ is the distance from the centre of the *i*-th municipality to the centre of the CBD. The higher the *ADC*, the more dispersed the region. In comparison with *PJ*, this indicator weights the centralization with a pure morphological element, the distance from the CBD, hence it is less affected by the possible differences in the administrative boundaries of single municipalities.

As in the PJ index, also the *ADC* index has the implicit assumption of monocentricity of the region. However, it is able to take into account the physical distribution of activities within the whole territory of the urban regions, taking into account elements like the physical distance that separate, on average the localization of the employment.

Another approach is the one by Lee (2007). In his contribution on the economic effects of spatial structure, Lee proposed a modified version of an indicator proposed by Wheaton (2004). Lee's measure of centralization can be computed as follows:

$$CENTR = \frac{\left(\sum_{i=1}^{N} P_{i-1} DCBD_i - \sum_{i-1}^{N} P_i DCBD_{i-1}\right)}{DCBD^*} \tag{24}$$

where P_i is the cumulative proportion of population in the *i-th* municipality within a given province; $DCBD_i$ is the distance of the *i-th* municipality from the central municipality, which for simplicity is called "Central Business District" (CBD); and DCBD* is the distance of the outermost municipality from CBD and approximates the radius of a region with a hypothesized circular form. All municipalities must be sorted in ascending order by the distance from CBD. *CENTR* index ranges from -1 to 1, where 1 indicates perfect centralization. This measure is focused on morphology and explicitly considers the physical proximity (distance) between economic activities located in the region.

2.4 Polycentricity and Dispersion: links and overlaps

Figure 2.11 illustrates the concept of polycentricity and dispersion by showing the extremes. From the survey that has been carried out in previous sections, it emerges that polycentricity and dispersion have some points in common and could sometimes overlap: "At what number of centres polycentrism ceases and sprawl begins is not clear" (Gordon and Wong, 1985, p. 662).

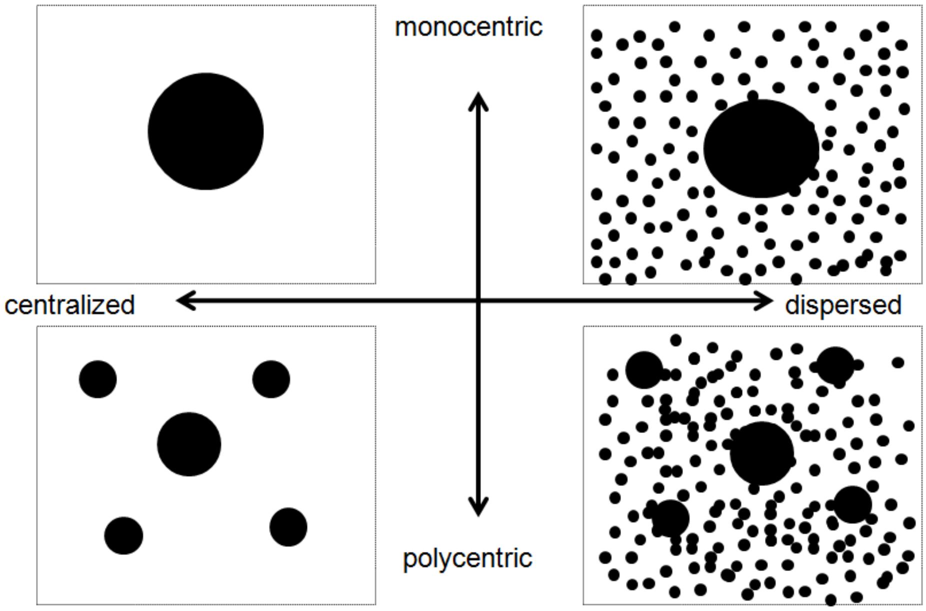


Figure 2.11: Polycentricity and dispersion

Polycentricity can be the result of dispersed urban areas, for instance in the case of 'Edge cities' (Garreau, 1991), which are sub-urban areas in which functions are decentralized from centres and are characterised by high level of accessibility (usually they are found in shopping malls or highway interchanges). Polycentric areas can also emerge from patterns of 'decentralised concentration', which is a re-distribution of economic activities from the Central Business District towards undeveloped sub-centres (Frey, 1999). However, this process may also result simultaneously in both the emergence of sub-centres – i.e. in polycentric structure – and urban sprawl.

In Europe, including Italy, urban growth that took place in many regions determines a process of territorial coalescence of pre-existing independent centres (Calafati and Veneri, 2012). In this case, if those centres have comparable size and there is no dominant centre, the region will be polycentric. The process may also cause urban dispersion, if the pre-existing centres lack open space between them.

So, the distinction between polycentricity and dispersion may be unclear. The outcome is also dependent on the elementary units of analysis that are taken into account to measure polycentricity. The larger the unit of analysis, the more unclear is the distinction between polycentricity and dispersion.

2.5 APPENDIX: Polycentricity in Italian regions

2.5.1 The selection of indicators

The resident population in Italian municipalities at the date of the last General Census (2001) was used as a proxy for the economic activity in regions. Regarding morphological measures, two indicators were considered. The first is the weight of the prime city over the total regional population. The second is the estimation of the rank-size coefficient for each region, where size is measured by population, taking municipalities as the basic units of analysis (see section 3.1). Table 2.1 reports the results of rank-size estimations. The estimations considered the rank-size equation in the Lotka form, where size is the dependent variable and rank the independent variable. Hence, the lower the (absolute) value of the estimated coefficient, the higher the polycentricity.

Regarding functional measures, data regarding daily work commutes were used (for 2001) as a proxy for the relational densities among cities. Again, Italian municipalities were taken as the unit of analysis. As with the morphological dimension, in order to overcome the problem of the number of units to be accounted for in each region, the threshold applied was the same as the one used for rank-size estimations. *Ordinary Polycentricity* and *Entropy Index* were then computed. Some descriptive statistics are provided in Table 2.2.

Table 2.1: Rank-size estimates for Italian regions, 2001

Region	Beta	t-statistic	Number of observations
Piemonte	–0.800***	-11.03	69
Valle d'Aosta	–0.772 **	-3.32	14
Lombardia	–0.701***	-18.15	158
Trentino Alto Adige	– 0.923***	-20.15	36
Veneto	– 0.709***	-19.42	80
Friuli Venezia Giulia	– 0.852***	-10.78	29
Liguria	– 1.212***	-8.31	18
Emilia – Romagna	– 0.942***	-15.19	30
Toscana	– 0.785***	-35.96	29
Umbria	– 0.962***	-15.83	9
Marche	– 0.683***	-12.58	22
Lazio	– 0.811 **	-3.44	34
Abruzzo	– 0.788***	-21.58	23
Molise	– 0.937***	-23.42	17
Campania	– 0.639***	-6.69	53
Puglia	– 0.686***	-45.67	34
Basilicata	– 0.773***	-11.66	22
Calabria	– 0.824***	-54.77	46
Sicilia	– 0.794***	-13.06	38
Sardegna	– 0.862***	-36.95	32

Note: ***= significant at 1%, **= significant at 5%

Table 2.2: Selected indicators of polycentricity, Descriptive statistics.

Variable	Mean	Median	Std. dev.	Minimum	Maximum
Primacy	0.163	0.127	0.111	0.060	0.498
Rank-size	– 0.823	– 0.797	0.130	– 1.212	– 0.639
Ordinary Polycentricity	0.619	0.624	0.103	0.384	0.841
Entropy Index	0.511	0.522	0.073	0.292	0.590

2.5.2 Relationships between morphological and functional indicators

In order to examine the relationships among the indicators of polycentricity, Pearson (*r*) correlation coefficients were computed (Table 2.3). With reference to the morphological dimension, rank-size estimations and the population share of the largest city are consistently negatively correlated. Then, referring to the functional dimension, we see that *OP* and *EI* are not correlated: this reflects the fact that *OP* may account for polycentricity, while entropy indicates the dispersion of economic activity. Those two aspects do not seem to be related to each other in the case of Italian regions.

Table 2.3: Correlation coefficients between indicators of polycentricity

	Rank-Size	Primacy	OP	EI
Rank-Size	1	– 0.39	0.47	0.56
Primacy		1	– 0.12	– 0.79
Ordinary Polycentricity			1	0.07
Entropy Index				1

Regarding the relationship between functional and morphological measures, Table 3 shows that the rank-size estimator correlates with both functional indicators, while the latter negatively correlates with the weight of the main city. Thus a higher level of morphological polycentricity is associated with a higher level of functional polycentricity and with a higher level of entropy. When the morphological polycentricity is measured by rank-size coefficients and the functional dimension by *OP*, results from the two approaches are consistent (r= 0.47). The same relationship holds for the percentage of the largest city instead of the rank-size, but to a lesser extent (r= –0.12). These results suggest, as expected, that although polycentricity is tackled from the two different perspectives, results are fairly consistent.

A deeper look at the relationship between functional and morphological polycentricity (rank-size vs. *OP*) enables us to identify four groups of regions[22] (Table 2.4, Figure 2.12, Figure 2.13). Unsurprisingly, the main regions in Northern Italy (Piedmont, Lombardy, Veneto) show high values of polycentricity both from the morphological and functional perspectives. The emergence of polycentric structures in Lombardy, for instance, has been investigated by Camagni and Salone (1993, p. 1062). It is also worth noting that the regions with the highest values of both morphological and functional polycentricity are those with the highest population (Table 4). This finding is consistent with the idea that the number of centres increases with the regional population (Fujita and Ogawa, 1982).

[22] The threshold applied to discriminate between the high or low value of polycentricity is given by the mean values of rank-size estimates and *OP* results.

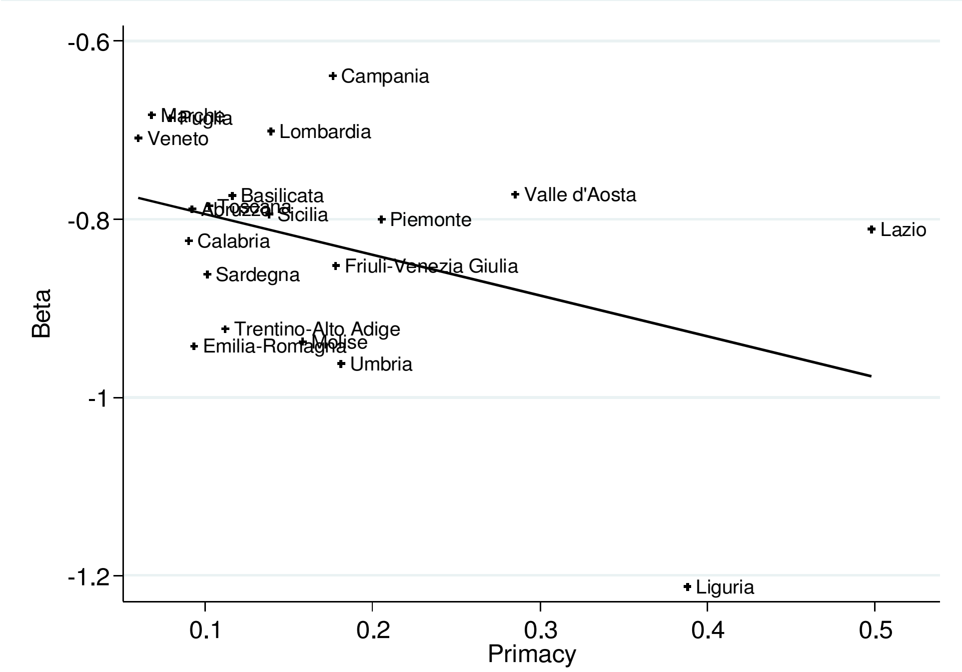


Figure 2.12: Rank-size estimator and primacy index

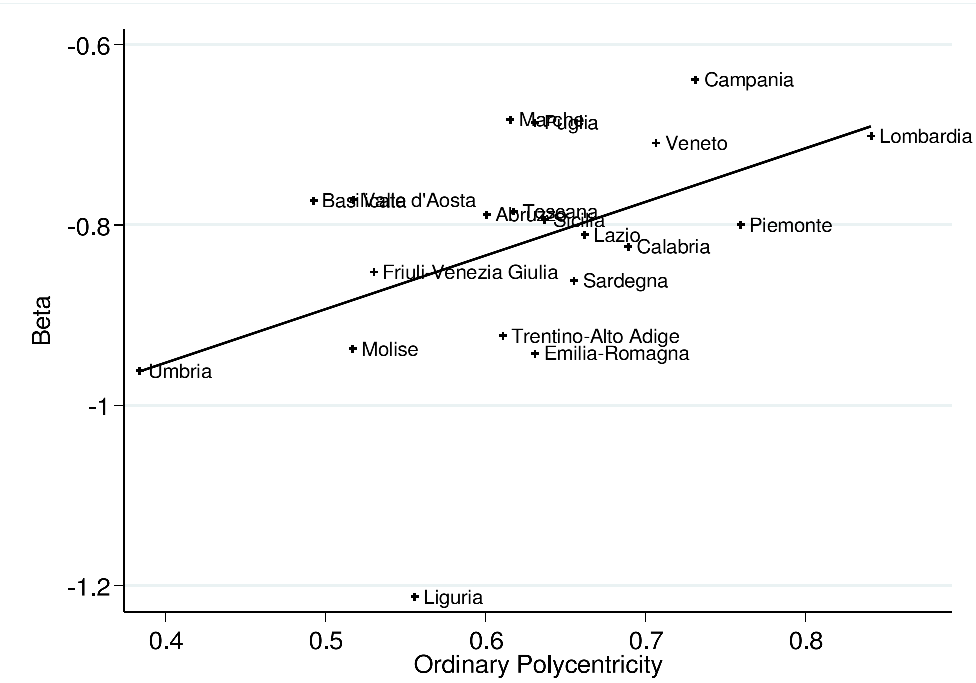


Figure 2.13: Rank-size estimator and Ordinary Polycentricity

Table 2.4: Levels of morphological and functional polycentricity in Italian regions

Region	Population	Cluster of Polycentricity (Morphological-Functional)
Lombardia	9,032,554	High - High
Campania	5,630,280	High - High
Lazio	5,140,371	High - High
Sicilia	4,966,386	High - High
Veneto	4,380,797	High - High
Piemonte	4,302,565	High - High
Puglia	4,031,885	High - High
Emilia-Romagna	3,909,512	Low-High
Toscana	3,529,946	High-Low
Calabria	2,070,203	Low-High
Sardegna	1,648,248	Low-High
Liguria	1,676,282	Low-Low
Marche	1,429,205	High-Low
Abruzzo	1,249,054	High-Low
Friuli-Venezia Giulia	1,197,666	Low-Low
Trentino-Alto Adige	890,360	Low-Low
Umbria	811,831	Low-Low
Basilicata	610,528	High-Low
Molise	330,900	Low-Low
Valle d’Aosta	115,938	High-Low

2.5.3 Polycentricity and economic performance in the Italian regions

This section investigates to what extent the degree of polycentricity of Italian regions correlates with the major (spatial) normative goals that have been emphasised by the ESDP: social cohesion, economic growth and sustainable development. Economic theory can help to explore the reasons why polycentricity should help to achieve such policy aims. In fact, it has long been known that, despite the decrease in transport and communication costs (which should lead to the dispersion of economic activity), cities continue to maintain their role as the engines of economic development for regions and countries. The size and the density of the city foster several types of *agglomeration economies*. These advantages increase the productivity of the firms that cluster in space, thus encouraging concentration (*static* externalities). Moreover, cumulative causation taking place in urban environments (see, e.g., De Groot et al., 2009) can lead to higher innovation and growth, contributing in turn to concentration (*dynamic* externalities). These mechanisms are confirmed by the fact that productivity and (per capita) income levels increase with urban size (Glaeser and Gottlieb, 2009). However, larger cities can also face negative externalities, such as traffic congestion, rising prices, pollution and other adverse effects on the economy, society and environment, which may counterbalance the benefits of agglomeration (Capello and Camagni, 2000, p. 1485).

Polycentricity can be viewed as a particular manifestation of the spatial agglomeration of activity. The morphological indicators proposed in the previous section – the role of the prime city and rank-size distribution – might account for such agglomeration effects. However, cities within a region can also be viewed as *nodes* that interact within a *network*. Hence, regional development can be fostered not only by agglomeration, but also by network externalities (Boix and Trullén, 2007), which can be generated by the networking between "major agglomerations and their hinterland" and by "dense networks of big or middle sized cities" (Barca, 2009, p. 18)[2]. The main idea behind the virtuous effects attributed to polycentricity is that network externalities within regions can substitute simple agglomeration externalities. They can do this by allowing the emergence of *regionalised* urbanisation economies (Meijers and Burger, 2010), thus allowing for a more balanced economic development. Within this framework, functional indicators such as *EI* and *OP* might take into account the structure of network relationships inside regions.

One point that deserves particular attention is the link between polycentricity and environmental sustainability. Land use is the first aspect that is worth addressing. Italian cities are growing spatially, even in regions characterised by a steady population. As a result, there is increasingly more pressure of urban fabric on open space (agricultural and natural land), leading to the well-known phenomenon of urban sprawl. In fact, since the 1950s almost all Italian regions have been involved in major urban expansion, sometimes following a scattered pattern. While initially this was mainly seen as being caused by a population movement towards cities, more recently it also seems to be due to other factors, such as the change of households' preferences towards housing in low-density and newly urbanised areas (Camagni *et al*., 2002) and technological progress, especially in the field of transport and communication technologies. The latter has enlarged individual circadian cycles and it has even re-shaped the functional boundaries of urban areas (Calafati and Veneri, 2013).

Thus a balanced polycentric pattern - conceptualised as a model of spatial organisation midway between compact/monocentric and dispersed areas (Camagni et al., 2002, p. 52) - would be able to optimise land use. This could be done by allowing territories to expand spatially, without paying some of the costs of dispersed development (Muñiz et al., 2006). However, "there is little consensus on whether polycentric metropolitan form represents compactness or sprawl" (Tsai, 2005, p. 141). Urban sprawl is a multidimensional phenomenon, which is characterised by several aspects, such as the metropolitan size, the density, the degree of distribution and centrality of population (*ibid.*). The polycentricity indices proposed here do not explicitly take into account all the dimensions of sprawl. However, the weight of the prime city gives an insight into the metropolitan size. Rank-size estimations then capture the degree of distribution of the population, while *OP* and *EI* give an overview of the centrality and degree of clustering of centres.

Finally, a key link between spatial structure and environment is given by the emissions, and can be analysed by looking at commuting patterns. Some authors have recognised various environmentally positive effects of polycentricity on commuting flows (Tsai, 2001; Veneri, 2010), especially because of the proximity between work and home (Gordon et al., 1989). In fact, a pure monocentric region involves a huge amount of flows directed towards the centre, causing congestion and higher social costs, while a polycentric region leads to more sustainable commuting patterns, encouraging the proximity between housing and work. In addition, the emergence of high-density sub-centres could lead to more efficient supply of public transport, especially as compared to sprawled areas, which in contrast foster the use of private transport.

In order to verify whether or not the degree of polycentricity is associated with the key variables of economic and environmental performance, a correlation analysis was carried out. All the variables taken into account are reported in Table 2.5, while results of the correlation analysis are reported in Table 6. Given the very small number of observations, correlation coefficients represent a good way to explore the relationships discussed above – even if only in descriptive terms. Table 2.6 presents some interesting results, which are further verified through a regression analysis (Table 2.7). Regression analysis enabled us to make sure that the signs and statistical significances of the relationships are robust to the inclusion of other variables, which are supposed to explain the phenomena under study.

Table 2.5: variables used in the analysis

Variable name	Conceptual meaning	Description	Year	Source
rank-size	morphological polycentricity	rank-size coefficient (β)	2001	Istat
op	functional polycentricity	Indicator of functional polycentricy (Green, 2007)	2001	Istat
primacy	monocentricity	weight of prime city's population over total regional population	2001	Istat
entropy	polycentricity/dispersion	entropy index from commuting flows (Limtanakool et al., 2007)	2001	Istat
gini	social cohesion (income distribution)	Gini index on distribution of per capita income	2003	Istat
gdp-capita	economic competitiveness (static)	per capita gross domestic product	2000	Istat
gdp-growth	economic competitiveness (growth)	growth rate of per capita gdp	2000	Istat
lab-prod	economic competitiveness (static)	per capita labour productivity	2001	Istat
prod-growth	economic competitiveness (growth)	growth rate of per capita labour productivity	2001-2008	Istat
res_land	environmental sustainability (land use)	square metres of per capita residential land	2000	European Environment Agency
res_land_gr	environmental sustainability (land use)	growth of per capita residential land	1990-2000	European Environment Agency
fabric	environmental sustainability (land use)	area used for discontinuous urban fabric over total territory	2000	European Environment Agency
licences	environmental sustainability (land use)	m^3 of new buildings authorised per 100 inhabitants	2001	Istat
energy	environmental sustainability (energy and emissions)	per capita energy use in the transport sector	2000	Enea
emissions	environmental sustainability (energy and emissions)	per capita greenhouse gas emissions	2000	Ispra SINANET

The low number of observation units taken into account (the 20 Italian regions) limited the number of dependent variables to be taken into account by the regression analysis. Hence the a maximum of two dependent variables were selected for each key dimension – those which led to the most interesting results – and focusing on the two most specific indicators of polycentricity, i.e. rank-size and *OP*. Social cohesion was analysed by means of a Gini Index on income (*gini*), while economic competitiveness by means of labour productivity, both in levels and using the 2000-2008 growth rates. Finally, environmental sustainability was considered in terms of both land use by focusing on the percentage of discontinuous urban fabric over the total territory (*fabric*), and energy consumption by focusing on per capita energy consumption for transport purposes (*energy*).

Given the limited number of observations (20), only one or two control variables were included in the regression equation, basing this choice on the literature. Hence, the gross domestic product (GDP) per capita and its past growth rate were included in the equation for income distribution (Meijers and Sandberg, 2008) and GDP per capita was included in the equation for energy consumption (Poumanyvong and Kaneko, 2010). The equation for land use was utilized to control for the recent growth in residential land, under the hypothesis that recent urbanisation followed dispersed patterns (Camagni et al., 2002). Finally, since the link between spatial structure and economic growth is only indirect, a control for recent economic growth rates was included in order to take into account the path dependence of the economic process. In the productivity level equation, the share of people aged over 65 in 2001 (*over65*) was also included as a demographic and social relevant variable, as in Grassmueck and Shields (2010).

Table 2.6: Pearson correlation coefficients between the degree of NUTS-2 polycentricity and ESDP's key dimensions of performance

key dimension	variable	rank-size	primacy	op	entropy
Social cohesion	gini	0.23	0.31	0.45	– 0.31
Economic performances	gdp-capita	– 0.15	0.26	0.12	– 0.03
	gdp-growth	0.06	0.19	– 0.11	– 0.20
	Lab-prod	– 0.12	0.45	0.40	– 0.35
	lab-growth	– 0.13	0.19	– 0.42	0.15
Environmental sustainability	res-land	0.27	– 0.08	0.65	– 0.07
	res-land-gr	– 0.25	0.02	-0.31	0.18
	fabric	0.13	0.11	0.57	– 0.97
	licenses	0.12	– 0.54	0.13	0.39
	energy	– 0.18	0.33	– 0.19	– 0.02
	emissions	– 0.19	0.07	0.21	– 0.28

Table 2.7: Regression results for the analysis of the role of polycentricity on key performance (t-statistics in italic)

	Income distribution (Gini)		Labour productivity per capita		Growth of lab. product.		Discontinuous urban fabric		Energy for transport	
constant	0.378	0.315	43.555	15.348	0.344	0.343	0.016	–0.033	10.350	44.323
	0.000	*0.000*	*0.000*	*0.164*	*0.000*	*0.000*	*0.496*	*0.131*	*0.554*	*0.007*
gdp-gr-96-01	0.000	– 0.144								
	1.000	*0.388*								
gdp-capita	0.000	0.000					0.000	0.000	0.003	0.003
	0.195	*0.025*					*0.015*	*0.014*	*0.000*	*0.000*
lab-prod					–0.002	–0.002				
					0.095	*0.278*				
Prod-gr-95-00			–27.528	–27.464	–0.490	–0.433				
			0.043	*0.021*	*0.012*	*0.039*				
growth res land							–0.168	–0.131		
							0.020	*0.035*		
over65			37.856	81.892						
			0.279	*0.009*						
rank-size	0.038		1.342		0.000		0.011		–7.518	
	0.459		*0.884*		*0.998*		*0.683*		*0.695*	
OP		0.149		29.922		–0.042		0.067		–49.794
		0.013		*0.010*		*0.564*		*0.029*		*0.026*
R^2	0.184	0.432	0.230	0.552	0.359	0.372	0.485	0.617	0.685	0.765

2.5.3.1 Polycentricity and social cohesion

To assess how the degree of polycentricity relates to social cohesion, we focused on the income distribution in regions, measured by the Gini Index. Ranging from 0 to 1, 0 (1) represents a perfectly equal (unequal) distribution of income. Results show that the more polycentric the regional shape - measured with both morphological and functional indexes - the more unequal the income distribution (Table 2.6). The same holds for the weight of the largest city: the higher the population living in the prime city, the less equal the distribution. The negative correlation between polycentricity and income distribution is particularly highlighted by the functional polycentricity (Figure 2.14; r=0.4). These findings are different from the conclusions in the ESDP, but consistent with the results by Meijers and Sandberg (2008), who carried out a European comparison at a country level. The results of the correlations are also consistent with those from regression analysis, which confirms the signs and partially the significance of the coefficients (Table 2.7). Entropy is the only measure that negatively correlates with income distribution. However, as has already been noted, entropy could indicate a dispersed pattern of development rather than the polycentric spatial organisation of the regions to which it is applied.

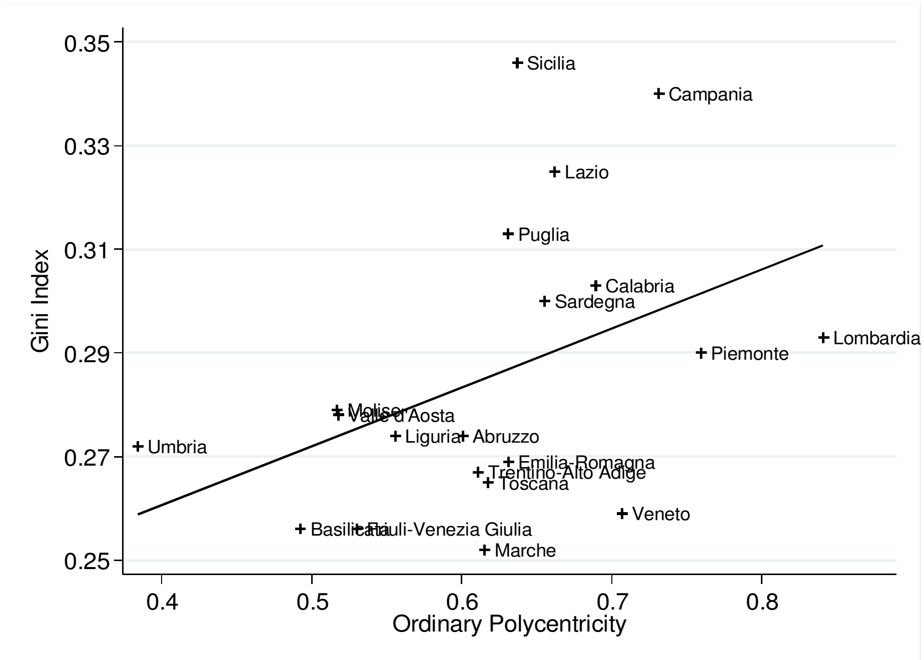


Figure 2.14: Gini index of income distribution and Ordinary polycentricity

2.5.3.2 Polycentricity and economic competitiveness

Four indicators were used in order to approximate economic competitiveness: labour productivity and regional GDP, both in levels (referring to 2001) and in growth rates 2000-2007. The degree of concentration of population in the prime cities correlates positively with all the economic competitiveness indicators (Table 2.6), especially with those regarding "static" measures (GDP and Labour productivity in levels). This suggests that urbanisation externalities arising in large urban environments might be important drivers for the economic performance of the region. On the other hand, regions characterised by a pattern of spatial organisation that may be called "polycentric dispersion", as accounted by the *EI*, are associated with lower levels of productivity and GDP growth.

Rank-size coefficients are poorly related to economic performances, while *OP* correlates highly negatively with labour productivity growth but, at the same time, correlates positively with the level of labour productivity (r=0.40). Regions that show a high degree of functional polycentricity – where network externalities are supposed to play a role – seem to be associated with a higher level of productivity. This result is confirmed by the regression analysis which, on the other hand, does not confirm the negative association between functional polycentricity and productivity growth (Table 2.7). This would suggest that polycentricity poorly influences regional economic performance.

2.5.3.3 Polycentricity and environmental sustainability

In order to verify to what extent polycentricity and environmental sustainability are linked in terms of land use patterns, a set of indicators was selected. The ratio of urbanised area compared to the total regional area was computed as an indicator of urban sprawl[23]. Since low-density settlements characterise urban sprawl, the ratio of the discontinuous urban fabric over the total territory was then computed[24] CORINE Land Cover, class 1.1.2 (Bossard et al., 2000).

The results show that the more polycentric the structure, the more land is needed for urban fabric. The positive correlation is particularly evident when accounting for the *OP* (Table 2.6). The same results hold when only the discontinuous urban fabric is considered (Figure 2.15). Both signs and significance of such a relationship were confirmed by the regression analysis. This would suggest that polycentricity, similar to sprawled patterns of development, is mainly related to a higher consumption of land.

Lastly, the number of building licenses (*licenses*) correlates negatively with the weight of the prime city and positively with the entropy, while there are no significant correlations with rank-size and *OP*. Hence, looking at the spatial development in terms of change in the demand for land does not highlight a role for polycentricity, while there is a positive correlation with spatial entropy.

[23] We considered Class 1.1 of the CORINE Land cover, "Urban fabric": Areas mainly occupied by dwellings and buildings used by administrative/public utilities or collectivities, including their connected areas (associated lands, approach road network, parking-lots). See Bossard et al. (2000) for the technical details.

[24] CORINE Land Cover, class 1.1.2 (Bossard et al., 2000).

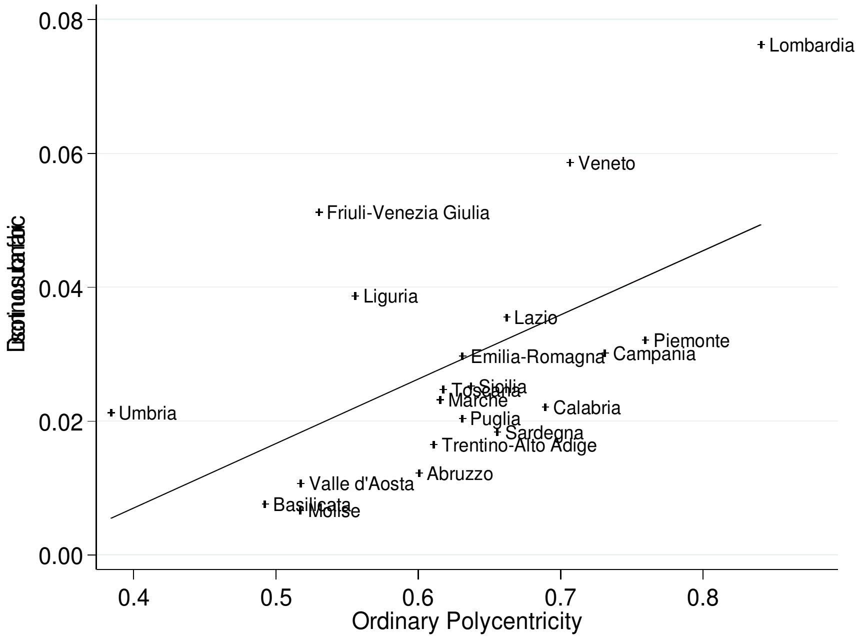


Figure 2.15: Discontinuous urban fabric and Ordinary Polycentricity

With reference to per capita energy use for transport (*energy*), the weight of the prime city shows a positive and significant correlation, while correlations with the other spatial indicators are very small in magnitude. However, signs of correlations give an indication that more polycentric regional structures, both from a morphological and functional point of view, are associated with less energy consumption (Table 2.6). This is confirmed by the regression analysis, which shows that the role of functional polycentricity is also statistically significant. This could be due to the highest use of public transport in polycentric regions. The correlation with the weight of the prime city suggests that monocentric regions show higher energy uses for transport.

Finally, when accounting for greenhouse gas emissions[25], the findings show a slight positive correlation with rank-size and *EI*. On the whole, it appears that greenhouses emissions are higher in functionally polycentric regions and smaller in dispersed regions. However, this latter evidence is still too weak to draw any firm conclusion.

[25] Tonnes of CO_2 equivalent per capita (CO_2, NO_x, methane; other sources and removals included), year 2000. Source: ISPRA SINANET (http://www.sinanet.apat.it/it/emissioni).

2.5.4 **Concluding remarks about polycentricity in Italian regions**

Since the 1990s the concept of polycentricity has gained a central role in the scientific debate on regional Economics and Planning. Following the ESDP, polycentric regions have been assumed to have the potential for virtuous performances– in terms of economic competitiveness, social cohesion and environmental sustainability. However, these hypotheses have not been corroborated with enough robustness. Moreover, despite the efforts to create new images and metaphors to conceptually represent polycentric regions, few attempts have been made to plan and regulate an efficient polycentric spatial organisation (Albrechts, 2001). A reason for these gaps, both in the analysis and in the policy actions, may be the fact that polycentric development is a fuzzy and multidimensional issue, involving several spatial scales and methodological approaches.

On the background of the current scientific and policy debates on polycentric spatial development, this work attempted to stimulate a discussion on the *concept* and on the *role* of polycentricity, by reflecting on several issues where it would be worthwhile to carry out additional research.

The first issue regarded how to measure polycentricity, by stressing the differences between the two main perspectives adopted to analyse the concept in the literature (morphological vs. functional). By considering the Italian NUTS 2 regions, the results of the analysis showed that notwithstanding the differences between functional and morphological approaches, the two dimensions are highly correlated.

The second aspect regarded the effectiveness of polycentricity as a normative goal. This issue appears to be particularly challenging both from a theoretical and empirical point of view and promises to continue to be a stimulating field of research for the near future. The aim was to discuss the theoretical justifications of the potential for superior performances of polycentric regions. Then, an empirical analysis was carried out, aimed to explore – following the ideas contained in the ESDP – to what extent the degree of polycentric development of Italian NUTS 2 regions is associated with various key indicators of economic, social and environmental performance. The results show that polycentricity in Italian regions is not always a virtuous model of spatial development, especially in terms of social cohesion. This is in contrast with the idea of ESDP, but consistent with other European studies on this topic (Meijers and Sandberg, 2008). Correlations among polycentricity and environmental indicators are also not univocal, and the same happens when competitiveness is taken into account.

In summary, then, the analysis confirms the idea that the polycentric spatial structure – taken alone – is far from being an effective tool to reach those important policy aims highlighted by ESDP, at least when considering Italian NUTS 2 regions. However, a central point that must be clarified, especially from a theoretical perspective, is the spatial scale at which polycentricity can exert a virtuous role – in other words, the level at which *regional* externalities can exploit – and thus the appropriate scale for potential policy actions. In order to do that, the concept of polycentricity, as well as its measures, needs to be developed further on by analysing both the dimensions involved and the appropriate spatial scale.

PART II

3 Spatial Structure and Productivity in Italian NUTS-3 Regions

This chapter investigates how spatial structure affects labour productivity in Italian provinces. The analysis draws on agglomeration theories, and analyzes whether agglomeration benefits are dependent on the way activities are spatially organized within regions. Urban spatial structures have declined in terms of size, dispersion and polycentricity. Using instrumental variables and spatial econometric techniques, the effects of spatial structure for the 103 Italian NUTS-3 regions have been assessed. The findings include negative impacts of both polycentricity and dispersion and a positive impact of size.

3.1 Introduction

As highlighted in the Introduction of the thesis (Chapter 1), contemporary urban regions have become very complex and heterogeneous in terms of their size and structure. Cities have been expanding and becoming a regional phenomenon, both from a physical and a functional point of view. As a consequence, the growth of cities has affected the spatial structure of the regions where they are located, at least in terms of dispersion and polycentricity. On the one hand, activities are either concentrated in (dense) centres or dispersed across the territory. On the other hand, the core of economic activity, traditionally concentrated in city centres, has tended to move towards new (sub) centres, forming polycentric urban regions.

The changes that have characterized metropolitan regions have inspired research on agglomeration economies and optimal spatial structure, especially with reference to the concepts of size, polycentricity and dispersion. In addition, several concepts, such as

Polycentric Urban Regions, Edgeless Cities, Mega City Regions, etc., have been introduced in order to identify the boundaries of the “new” spaces where economic processes take place. Using Alonso’s concept of “borrowed size”, it has been argued that cities and, as a consequence, agglomeration economies have regionalised. Accordingly, regional urban systems characterized by strongly interconnected centres are assumed to share the benefits of agglomeration, without incurring the diseconomies that characterize (large) monocentric regions, such as congestion and high land prices.

However, few empirical studies have focused on understanding whether regional spatial structures play any economic role. The existing literature is often characterized by a reductionist approach and tends to use the basic measures of spatial structure, ignoring the functional relationships in centres and focusing only on regional morphological features.

The aim of this chapter is to verify whether spatial structure affects productivity in Italian NUTS-3 regions. After reviewing the literature, we quantify regional spatial structures in terms of *size*, *centralization-dispersion* and *polycentricity-monocentricity*. Having identified an aggregate production function including spatial structures factors as sources of productivity, a cross-sectional analysis is performed. We control for endogeneity and spatial dependence using instrumental variable estimations and spatial econometric techniques.

Our main findings show that larger regions perform better, and that higher centralization and monocentricity leads to higher productivity. This suggests that regionalised agglomeration economies do not replace single-centre agglomeration effects. In other words, physical proximity is still more important than relational proximity at a regional level. At the same time, we also found that the marginal effect of centralization decreases with the size of the region. Thus suggests that there may be effects due to congestion.

The chapter is organized as follows. Section 3.2 provides the methodological framework for the role of spatial structure on economic performance and reviews the literature. Section 3.3 proposes a simple model whose empirical setting is introduced in Section 3.4 and commented on in Section 3.5. Section 3.6 provides the conclusion and suggests further research on this topic.

3.2 The role of spatial structure for economic performance

The process of growth that has characterized the Italian urban system over the last century and a half have considerably affected the shape and structure of cities, both in terms of their physical dimension (*urbs*) and their social dimension (*civitas*). In fact, urban economic development and urban spatial structure are tightly linked (Parr, 1987). The massive structural changes caused by the Industrial Revolution, with both the demographic and urban transition, led to the physical expansion of cities, which increased their role as engines for regional economic growth (Hohenberg and Lees, 1985). Technological progress in transport, which started in the 19th century, allowed for a reduction in space and time constraints for households (Bertolini and Dijst, 2003). However, the distinction between urban and extra-urban environments still held, and cores of cities continued to maintain the role of centres for urban business: "people lived at low densities, but they worked at high densities" (Glaeser and Kahn, 2001, 3). With the advent of the post industrial age, this distinction no longer holds. Further progress on mass transport systems and the increase in private car use made daily activities less dependent on previous urban boundaries (Giuliano and Small, 1996). Jobs followed the residential activity, starting to spread as well (Glaeser et al., 2001). The de-coupling between *urbs* and *civitas* driven by dispersion is now evident in most urban regions.

Another feature of contemporary regional systems is the re-clustering of activities. If in the past the Central Business District (CBD) was a major focal point of the urban economy, as described by the Alonso-Muth-Mills Model, in recent decades activities have tended to re-cluster in new (sub) centres. *Polycentricity* may also be present when existing cities within the same regions become more interconnected. This type of decentralization characterizes (Western) European urban systems, which show higher land constraints and the less availability of open space, compared to American cities. In Europe, cities are traditionally linked to each other, with high relational densities and a physical proximity (Calafati, 2009). Thus, physical growth in cities has appeared more in the form of the coalescence of existing centres rather than the emergence of new cities. On the other hand urban hierarchy, which is shown by the size distribution of cities, appears quite stable (Duranton, 2007).

Regarding the spatial evolution of functional regions, Italy shows patterns that are similar to other countries of Western Europe. In fact, Italy has historically shown high degrees of urbanization (Malanima, 2005), thus core cities are determined and path dependent. In addition, cities tend to be integrated in terms of functions and mutual interactions: this is evident for instance in daily commuting flows.

3.2.1.1 A regionalization of agglomeration externalities?

Considering both the US and the European cases, it has been argued that one of the main consequences of the patterns of spatial development that have taken place over the last decades, is that the spatial extent of agglomeration externalities has extended beyond the administrative borders of the city. In other words, cities are becoming a "regional phenomenon" (Meijers and Burger, 2010). If this hypothesis is true, then it is worth understanding whether the extent to which activities are spatially organized within the region – e.g. centralized, dispersed or networked in a polycentric structure – can affect economic performance. To give an example, in centralized regions there is a higher physical proximity between economic agents, and ideas move more quickly than in dispersed regions (Jaffe et al., 1993).

However, the advantages of agglomeration can also be exploited in particular types of decentralized regions, characterized by polycentricity. In fact, they may be shared among a set of medium-sized centres, which "borrow" each other's size in order to achieve the critical mass needed to generate agglomeration economies (Alonso, 1973). This is likely to be the case when considering urbanization economies à la Jacobs, while Marshall-Arrow-Romer externalities are likely to be confined to the urban cores, or at an even lower scale (van Soest et al., 2006).

In order to share the benefits of agglomeration, activities should be not dispersed throughout the region, but concentrated in two or more centres, which must be physically close to one another and in strong relation to each other. In fact, single-node agglomeration economies can be compensated or substituted by the presence of several urban centres that interact with each other through network relations of complementarities or synergies (Camagni and Salone, 1993). These kinds of external economies can be conceptualized as network economies (Boix and Trullén, 2007), which have the specific feature of being shared by nodes that are physically separated but close to each other. Thus, a polycentric structure can, in principle, avoid the diseconomies of congestion that characterize large and monocentric regions. At the same time a polycentric structure has at least some of the advantages of large agglomerations by 'sharing' the agglomeration advantages and the functional specialization of each centre.

These ideas represent a theoretical rationale at the basis of current European and National strategies promoting polycentric development, especially in the European context. In fact, since the European Spatial Development Perspective (ESDP) was published in 1999, the concept of polycentric development ceased to be only analytical and began to assume a normative relevance as a strategic concept to promote both economic, social and sustainability goals (Davoudi, 2003). The ESDP has been followed by other policy statements and has stimulated subsequent research on polycentric spatial structures and social, economic and environmental performances. However, despite the general success of *polycentrism* in the policy agenda, *polycentricity* is still a fuzzy and vague concept and its effectiveness still needs to be corroborated with appropriate empirical research (Meijers, 2008). Policies aiming at polycentric development may thus lack a strong scientific rationale.

3.2.1.2 Existing literature

For more than thirty years, spatial structures and economic performance have been recognized as being strictly linked to each other (Parr, 1979; 1987). However, little empirical research, especially on an inter-urban scale, has been carried out in order to link these two dimensions. The gap between research on agglomeration economies and studies on spatial structure, noticed by Parr in 1979, still exists.

The wide literature on agglomeration mainly focuses on the size and density of activities as determinants to foster urban and regional growth (e.g. Ciccone and Hall, 1996; Rosenthal and Strange, 2004), "reaching the general conclusion that productivity rises with city size" (Cervero, 2001, p. 1652). In addition the literature on networks (Camagni and Salone, 1993; Capello, 2000) takes into account the hierarchies in city systems. However, this approach seems to focus on the *links* rather than on the structure of the nodes within regions. Moreover, the network approach does not seem to sufficiently consider physical proximity as a source of synergies.

From an empirical point of view, the works of Lee and Gordon (2007, 2011), Meijers and Burger (2010) and Fallah et al. (2011) explicitly investigated the effects of spatial structure on economic development for U.S. Metropolitan Areas (MAs). Fallah et al. (2011) investigated how the intensity of sprawl of U.S. MAs affects their level of productivity, and found a negative and significant relationship. Lee and Gordon (2007) studied the effects of spatial structure on economic performances, where the latter were measured with employment growth in the period 1990-2000. They found that spatial structure affects growth depending on city size: clustered MAs showed faster employment growth when they are small. However, they did not find any effect of decentralization (monocentricity or polycentricity). The results were confirmed by their further research, which considered net business formation as a proxy for economic performance (Lee and Gordon, 2011).

Meijers and Burger's contribution (2010) was based on Lee and Gordon's work. Again, U.S. MAs were investigated and labour productivity was taken into account as a measure for economic performance in 2000. Their findings showed that dispersion was not harmful for labour productivity and that polycentric MAs were characterized by better performance. However, polycentricity seemed to slow the positive effects of metropolitan size (i.e. large and monocentric areas perform bettered than large and polycentric ones) and was more efficient for smaller MAs.

Contrary to the latter findings, by analysing a cross-section of 47 US MAs, Cervero (2001) found that employment density and urban primacy are positively associated with worker productivity, thus corroborating the hypothesis of agglomeration economies at a metropolitan level. However, metropolitan size had no influence on productivity, similarly to what had been found by Ciccone and Hall (1996).

Regarding polycentricity, few analyses have been carried out to assess its role for economic performance. Of these, Vandermotten et al. (2007) found the positive effects of monocentricity on efficiency in European regions, expressed in GDP per capita. These findings have also been confirmed by Meijers and Sandberg (2008), which, however, used European countries as units of analysis. In all the above-mentioned works, polycentricity is expressed in terms of morphology and measured mainly with rank size distributions. We found no papers where this spatial dimension was dealt with by considering functional relationships between territorial nodes. This work also aims to contribute in this area.

3.3 The model

In order to investigate the effect of spatial structure on localised productivity, we start with a very simple model, on the basis of previous works by Ciccone and Hall (1996) and Ciccone (2002).

In our model, we use a Cobb-Douglas production function with constant returns of scale to measure the output of firms:

$$Y = AL^{\alpha}K^{\beta}N^{\gamma}H^{\varphi} \tag{25}$$

where traditional inputs have been included, such as labour (*L*), capital (*K*), land (*N*) and human capital (*H*). Equation (25) can easily be rewritten in an intensive form, by dividing both sides by *L*. Given constant returns to scale in the production function, this transformation yields:

$$y = Ak^{\beta}n^{\gamma}h^{\varphi} \tag{26}$$

with lower case letters indicating per unit of labour factors. *A* represents a firm's environment, hence it is a measure of total factor productivity. The latter, according to Rosenthal and Strange (2004, p. 2126), allows for the influence of agglomeration. This means that with the hypothesis of regionalizing agglomeration economies, total factor productivity is affected by the spatial structure (size, polycentricity-monocentricity and centralization-dispersion) of regions where firms are located. Hence, total factor productivity is assumed to be a function of spatial structure characteristics and other relevant factors, as in equation (27):

$$A_i = exp\left[\alpha_0 + \sum_{j=1}^{J}\theta_j X_{ij}\right] \tag{27}$$

where X_{ji} includes spatial structure variables – size, polycentricity and centralization – and other factors such as industrial diversity, sectorial specialization in high-productive activities and other location-specific characteristics (regional dummies). Regarding the variables of spatial structure, size catches the strength of urbanization economies. Centralization is the extent to which activities are located to close each other, thus it tells to what extent they are centralized in one single centre rather than being spread throughout a region. In addition, polycentricity reflects the extent to which a region is characterized by the presence of several connected central nodes. α_0 reflects the remaining part of total factor productivity which is not explained by the variables included.

Substituting (27) in (26) and log-transforming the result yields the following linear equation (28), which is used as the reference equation in the empirical analysis:

$$\ln(y) = \alpha + \beta \ln(k) + \gamma \ln(n) + \varphi \ln(h) + \sum_i \theta_i \ln(x_i) + \varepsilon \quad (28)$$

where ε is an independent and identically distributed error term.

3.4 Data and variables

3.4.1 Quantifying spatial structures

The rationale behind this work is that agglomeration externalities can play a role at a regional level, through a particular configuration of the spatial structure. In order to test whether this idea is supported with empirical evidence, it is necessary to identify and quantify the most important characteristics of spatial structure. In line with the literature in this field (Tsai, 2005; Lee and Gordon, 2007; Meijers and Burger, 2010), spatial structure is conceptually expressed with three main components: size and the two spatial dichotomies related to monocentricity-polycentricity and centralization-decentralization.

Size is easily measurable with a total regional population and accounts for the overall strength of any agglomeration forces at work in a particular area. However, by looking at size alone it is impossible to know the nature of agglomeration and how population, jobs and activities are spatially organized within each region. In this respect, the monocentricity-polycentricity dichotomy leads to a deeper characterization of spatial structure at a metropolitan or regional level. This thus helps us to understand to what extent activities are concentrated in the central urban node or, alternatively, distributed over several urban centres.

Although often conceptualized as a pure morphological concept, polycentricity has a functional dimension that needs to be taken into account when analysing the potential economic implications of different spatial structures. In order to quantitatively characterize this specific feature of spatial structure, it is necessary to adopt an indicator that is able to take into account not only the physical distribution of activities, but also the functional relation that takes place within a region.

Recent works in the literature have contributed to these kinds of measurements. One of the most suitable is the Special Functional Polycentricity index (P_{SF}) proposed by Green (2007: 2084). P_{SF} is based on two fundamental assumptions. The first is that a region can be defined as polycentric if it is characterized by two or more central nodes (Riguelle et al., 2007: 195). The second is that these nodes must be functionally linked to one another, where relationships among nodes are based on functional features such as synergies or complementarities. The P_{SF} index is built using commuting flows between municipalities analysed using network analysis tools. It is obtained following the formula indicated in (29) and discussed in Chapter 2:

$$P_{SF} = (1 - \frac{\sigma}{\sigma max})\Delta \qquad (29)$$

where $\sigma_{\eth}$ is the standard deviation of nodal in-degree within the MA N; $\sigma_{\eth\max}$ is the standard deviation of the nodal in-degree of a 2-node network (n_1, n_2) derived from N where d_{n1} = 0 and d_{n2} = value of the node with the highest value in N; and Δ is the density of the network. Nodal in-degree is the number of links that connect one given municipality with another municipality within the same region. As discussed in Chapter 2, P_{SF} combines the spatial distribution of centralities with the density of the functional relations – measured in terms of commuting flows – that take place within a region (Δ).

The third dimension that has been used to characterize regional spatial structure is the centralization-decentralization dichotomy. It is well known that over the last few decades almost all cities in Western countries have decentralized their population and jobs from their core cities into their respective hinterlands (Lee, 2007; Glaeser and Kahn, 2004). However, this process has taken different forms and has occurred with different intensities. While in some cases there has been a shift towards a polycentric spatial structure, in other cases a pattern of generalized dispersion has taken place (Gordon and Richardson, 1996; Lang, 2003). In order to measure the degree of centralization in Italian NUTS-3 regions, a very different indicator proposed by Lee (2007) was used, which is a modified version of an indicator proposed by Wheaton (2004):

$$CENTR = \frac{\left(\sum_{i=1}^{N} P_{i-1} DCBD_i - \sum_{i-1}^{N} P_i DCBD_{i-1}\right)}{DCBD^*} \qquad (30)$$

where P_i is the cumulative proportion of population in the i-th municipality within a given province; $DCBD_i$ is the distance of the i-th municipality from the central municipality, which for simplicity is called "Central Business District" (CBD); and $DCBD^*$ is the distance of the outermost municipality from CBD and approximates the radius of a region with a hypothesized circular form. All municipalities must be sorted in ascending order by the distance from CBD. This indicator ranges from -1 to 1, where 1 indicates perfect centralization. Compared with the polycentricity index, this measure is focused more on morphology and explicitly considers the physical proximity (distance) between activities located in the region.

3.4.2 **Dependent and control variables**

The other variables that were taken into account regard all the factors and controls that enter the production function specified in Section 3.1, as well as the geographical dummies and instruments that were included in the empirical analysis to achieve consistent estimations. All the variables are summarized in Table 3.1, together with descriptions and some basic statistics.

The dependent variable is labour productivity per worker, calculated as the ratio between the real GDP and the number of jobs in the private sector, where the data refer to 2001. The variable relative to the capital-labour ratio was computed using Paci and Pusceddu's (2000) estimations of regional fixed capital, which was subsequently attributed to each NUTS-3 region on the basis of employment shares. The land-labour ratio was computed using total regional areas, as reported in the Istat (the Italian National Institute for Statistics) Census of 2001. The variable of education (*graduates*) was computed as the share of graduates over the total number of residents older than 25 in 2001. The sectorial structure of each region was controlled for in two ways. First, through an index of productive diversity (*hhi*) – consisting of the inverse of the Herfindahl index at a three-digit level in the private sector. Secondly, the share of employment in the *FIRE* industries (Finance, Insurance and Real Estate) over total employment in the private sector was included in order to control for the spatial distribution of particularly high-productive sectors.

As far as instrument variables are concerned, variables relative to size and centralization were also computed using 1951 Census data. On the other hand, polycentricity was computed using 1991 data, which represent the first available data on commuting flows. Of the other instruments, *accidents* is the number of traffic accidents in 2001, *pivot_job* is the share of jobs in the central municipality over the total number of jobs in 2001, and *rank_size* is the estimated coefficient of a linear equation where the log of resident population in each consolidated municipality is regressed over the log of its rank. This variable is a standard measure of morphological polycentricity and acts as an instrument variable for the polycentricity-monocentricity spatial dimension.

On the basis of the two last dimensions of spatial structure that have been taken into account, Italian NUTS-3 regions can be classified on the basis of their degree of polycentricity and of centralization. Figure 3.1 represents this classification, where all observations (provinces) are marked as "high" or "low" on the base of the value above or under the average value of each indicator. The figure shows that there is not a specific territorial pattern of spatial structure, even if the majority of polycentric regions are located in the Northern part of Italy, both with high dispersion and high centralization levels. On average, monocentric regions are more present in the Centre and in the South of Italy.

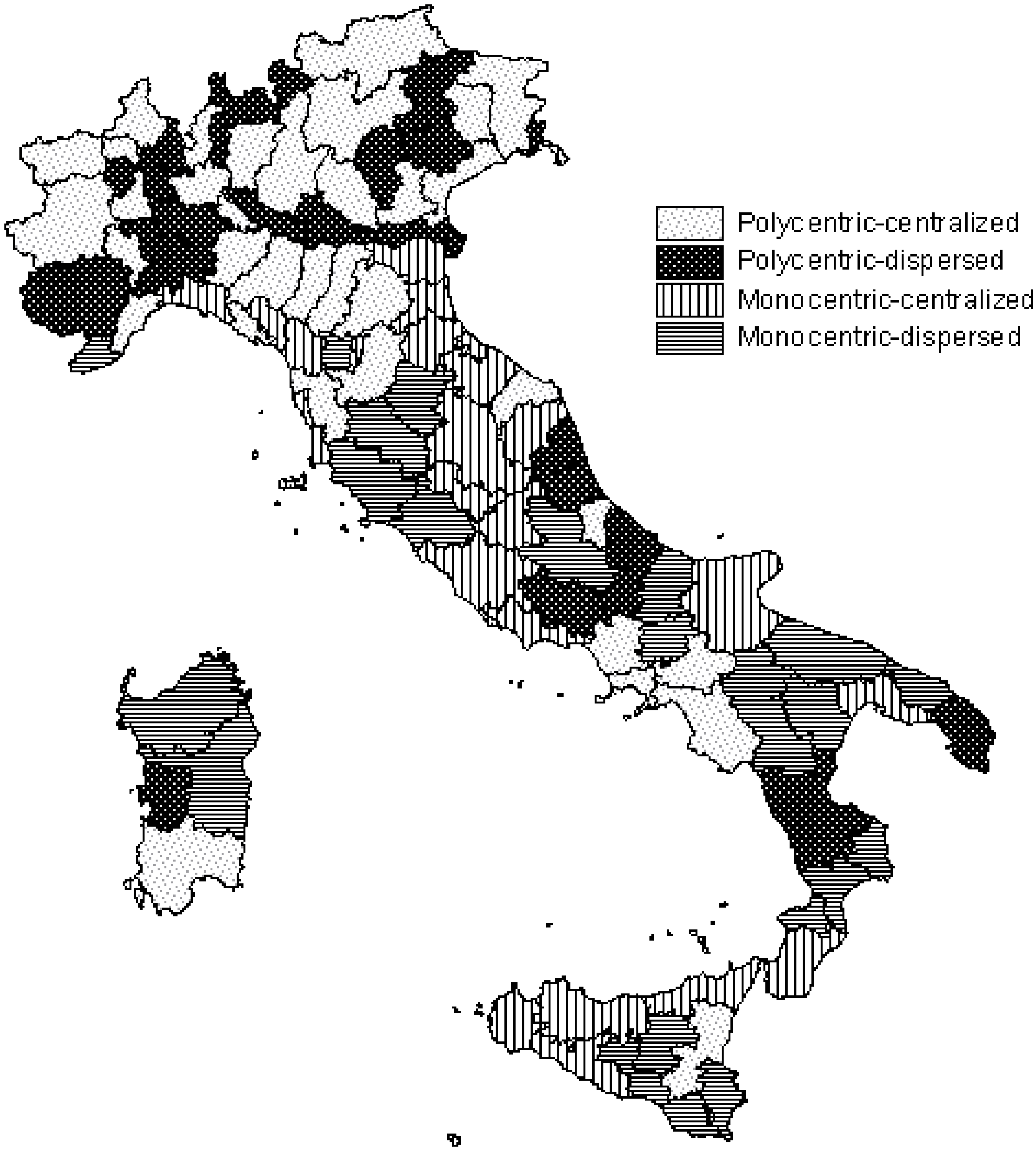


Figure 3.1: The spatial structure of Italian NUTS-3 regions: a simple taxonomy

Before introducing the estimation strategy that was used to verify the role of spatial structure characteristics on productivity, some basic empirical evidence is worth analysing. Figure 3.2 highlights the negative correlation of Italian NUTS-3 regions – between the degree of polycentricity and productivity levels in 2001. (This negative correlation is not particularly strong: the Pearson coefficient is –0.14). Figure 3.3 shows the clear positive association between the level of centralization of activities and productivity (p=0.34). Finally, there is also a clear and positive correlation between overall regional size and productivity (Figure 3.4).

The evidence highlighted in Figure 3.2 and Figure 3.3 is consistent with the hypothesis that Italian NUTS-3 regions benefit from agglomeration economies, and that a larger and higher centralization of activities is positive for economic performance. Diseconomies of congestion may not play an important role, considering the relatively small dimensions of the Italian NUTS-3 regions, except from a few metropolitan areas such as Rome, Milan, Naples and Turin. However, the analysis that follows is aimed at verifying whether this hypothesis is empirically founded. All non-dummy variables are in log form to allow for a straightforward interpretation of the estimated coefficients in terms of elasticity.

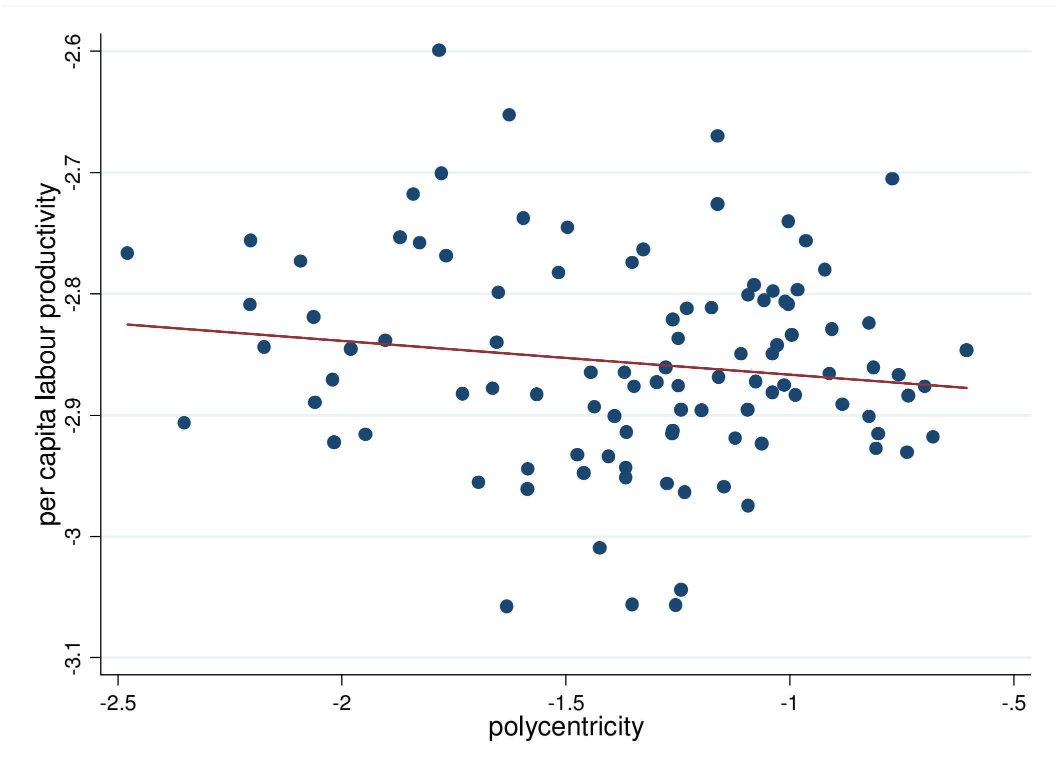


Figure 3.2: Polycentricity and per worker productivity levels (logs) in Italian NUTS-3 regions, 2001

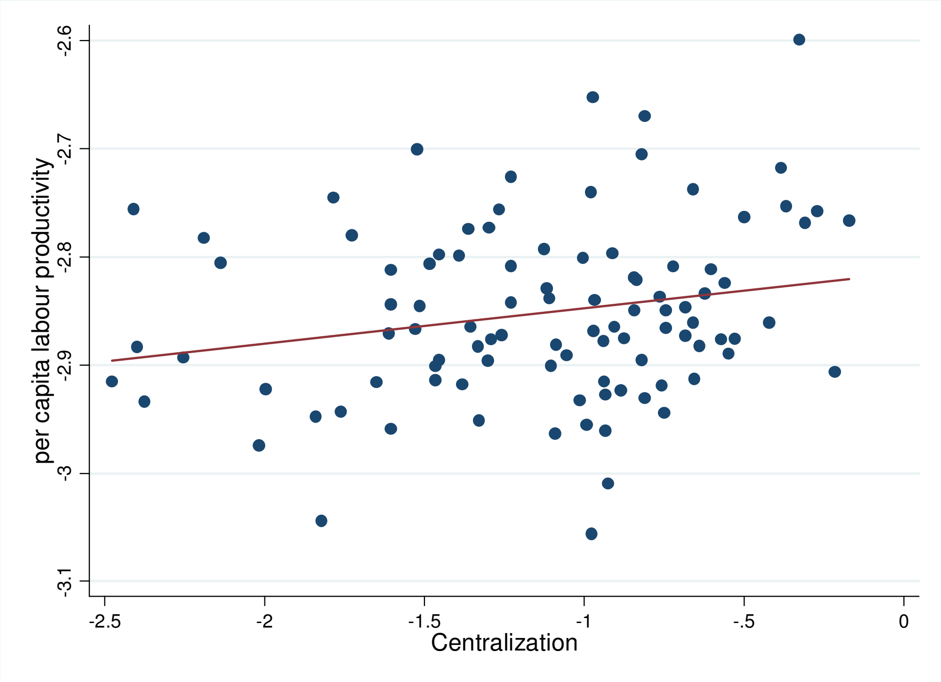


Figure 3.3: Centralization of the spatial structure and per worker productivity levels (logs) in Italian NUTS-3 regions, 2001

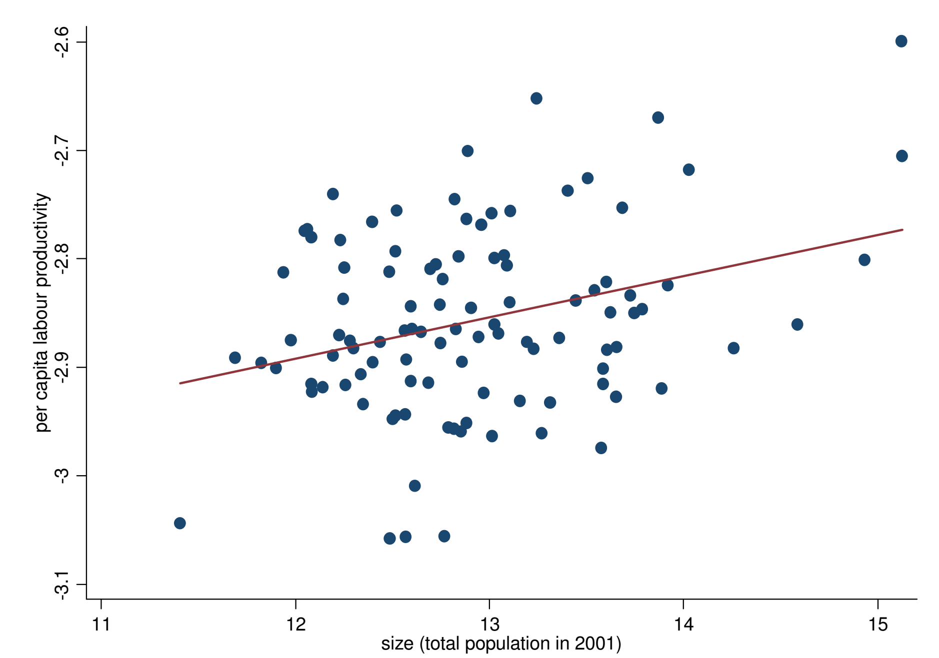


Figure 3.4: Regional size (total population) and per worker productivity levels (logs) in Italian NUTS-3 regions, 2001

Table 3.1: List of variables with description, source of data and basic statistics

Variables	Variable description	Data source	Mean	Std.Dev.	Min	Max
lab_productivity (ln	per capita labour productivity	Istat, 2001	-2.857	0.086	-3.058	-2.599
k_lab_ratio (ln)	kapital - labour ratio	Istat(2001), Paci and Pusceddu (2000)	-0.921	0.250	-1.221	-0.437
land_lab_ratio (ln)	total land area - labour ratio	Istat, 2001	0.942	0.930	-2.010	2.908
graduates (ln)	share of graduates over population older than 25	Istat, 2001	-2.466	0.167	-2.842	-1.878
size (ln)	total resident population	Istat, 2001	12.921	0.708	11.406	15.126
polycentricity (ln)	Green index of polycentricity (Green, 2007)	Istat, 2001	-1.341	0.416	-2.477	-0.605
centralization (ln)	Wheaton index of centralization (Wheaton, 2004)	Istat, 2001	-1.227	0.724	-4.605	-0.171
polyc91 (ln)	Green index of polycentricity for 1991	Istat, 1991	-1.697	0.641	-5.428	-0.750
centraliz51 (ln)	Wheaton index of centralization for 1951	Istat, 1951	2.305	0.023	2.201	2.372
size51 (ln)	total resident population in 1951	Istat, 1951	12.822	0.629	11.453	14.659
accidents (ln)	number of traffic accidents	Istat, 2001	7.412	0.834	5.380	10.360
rank_size (ln)	estimated size-rank coefficients (proxy of polycentricity)	Istat, 2001	0.254	0.214	-0.219	1.020
pivot_job (ln)	share of jobs in the central municipality	Istat, 2001	-1.123	0.397	-2.079	-0.130
hhi (ln)	inverse of the Herfindahl index of sectorial diversity for 2001	Istat, 2001	2.515	0.246	1.796	2.965
fire (ln)	share of employment in finance, insurance and real estate	Istat, 2001	-1.804	0.174	-2.216	-1.113
d_north	dummy variable: 1 value for Northern regions		0.447	0.500	0	1
d_centre	dummy variable: 1 value for Central regions		0.204	0.405	0	1

3.4.3 **Empirical specification and results**

In this section we investigate empirically whether urbanization and (regionalized) agglomeration externalities influence productivity in the Italian NUTS-3 regions. On the basis of the theoretical foundations in the previous section, an econometric model was estimated using different strategies. Table 3.3 shows the results of these estimations and also provides various diagnostic statistics.

3.4.3.1 Dealing with endogeneity

From an econometric point of view, one major issue is the possible endogeneity of spatial structure regressors. This is because conceptually there may be a problem of recursive causality, in the sense that the spatial structure of a region may be, at least to some extent, driven by the economic performance of the region itself (Parr, 1979; Graham et al., 2010). In other words, firms and households may be located in a region, or, more specifically, close to the central municipality because of the advantages of proximity, thus influencing the spatial structure of the whole region. As a matter of fact, although our aim was to test the hypothesis that spatial structure affects productivity, from an empirical point of view, this relationship may work in the other way round, i.e. productivity affects spatial structure. If this is the case, an ordinary least squares (OLS) estimation would not take this endogeneity issue into account and would lead to inconsistent estimates.

In order to correct for the endogeneity of regressors, one possible solution is to use a two-stage least squares (2SLS) estimator, using appropriate instrumental variables. Table 3.2 shows the results of a set of statistical tests to assess the hypothesis of endogeneity, as well as the strength and the validity of the instruments for each of the three variables of spatial structure and for the three variables taken together. For each column in Table 3.1, hence for each variable of spatial structure and for the set, both OLS and 2SLS regressions were run in order to conduct the tests. In addition, in order to assess the validity of the instruments (Sargan and Basmann tests) at least two instruments for each endogenous variable were included. Both Sargan and Basmann's tests are accepted, so that the null hypothesis that instruments are uncorrelated with the error term cannot be rejected and instruments can be considered as valid.

As far as the statistical significance of the instruments is concerned, Anderson's canonical correlation is always significant, as is the Cragg-Donald *F*-test, hence it is possible to reject the null hypothesis of weak instruments. In addition, by looking at Shea partial R^2, the significance of the instruments is confirmed, given the relatively high levels of all the correlation coefficients. Regarding the exogeneity test of the spatial structure variables, both Wu-Hausman and Durbin tests allow the null hypothesis, under which regressors are exogenous, to be accepted. As a consequence, OLS estimates are consistent. These results were confirmed for all the spatial structure variables, considered both separately and jointly (Table 3.2). The reasons why these variables are exogenous are in the viscous nature of spatial structures. The organization of activities in space only changes in the long run, and cannot be affected easily by short term economic dynamics (Lee and Gordon, 2007). In addition, the Italian – and maybe European – regional spatial structure is mainly the result of the changing relations and equilibriums between existing urban nodes. The spatial evolution of these nodes, in turn, may have been affected by territorial coalescence, which occurs in the long run (Calafati, 2009).

Table 3.2: First stage results of the two-stage least-squares (Model 2) regressions on per worker labour productivity

	Size	Polycentricity	Centralization	All
Instruments				
	population in 1951; car accidents in 2000	polycentricity in 1991; rank-size coefficients in 2001	centralization in 1951; share of jobs located in central municipality	all previous instruments
Relevance				
Anderson canonical correlation	95.25 ***	83.38 ***	49.51 ***	47.74 ***
CD F-test	558.96 ***	193.35 ***	42.12 ***	12.82***
Critical value CD (10% relative bias)	19.93	19.93	19.93	7.77
Shea partial R^2				
Size	0.925			0.901
Polycentricity		0.810		0.760
Centralization			0.481	0.477
Validity				
Sargan statistic	0.207	0.198	0.098	0.312
Basmann statistic	0.183	0.175	0.087	0.270
Exogeneity				
Wu-Hausman *F*-test	2.255	0.004	0.970	1.132
Durbin	2.490	0.004	1.086	3.787
Observations	103	103	103	103
Regressors	11	11	11	11
Instrumentes	12	12	12	14
Excluded instruments	2	2	2	6

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 3.3: Estimation results. Dependent variable: *lab_productivity*.
Robust standard errors are reported in brackets.

	Model 1: OLS		Model 2: 2SLS		Model 3: S2SLS	
intercept	-3.015	(0.273)***	-3.093	(0.267)***	-1.989	(0.685)***
k_lab_ratio	0.195	(0.043)***	0.194	(0.040)***	0.120	(0.056)**
land_lab_ratio	0.005	(0.010)	0.007	(0.009)	0.005	(0.009)
graduates	0.035	(0.064)	0.031	(0.061)	0.038	(0.057)
d_north	0.118	(0.029)***	0.119	(0.029)***	0.083	(0.036)**
d_centre	0.050	(0.023)**	0.051	(0.022)**	0.033	(0.025)
hhi	-0.062	(0.041)	-0.067	(0.039)*	-0.069	(0.037)*
fire	0.043	(0.071)	0.025	(0.066)	0.038	(0.060)
size	0.043	(0.016)***	0.047	(0.016)***	0.041	(0.015)***
polycentricity	-0.043	(0.021)**	-0.042	(0.022)*	-0.036	(0.022)*
centralization	0.019	(0.009)**	0.028	(0.012)**	0.027	(0.011)**
Wy					0.355	(0.198)*
N. observation	103		103		103.000	
Squared R	0.500		0.495		0.567	
F test	10.61	***	115.19	***	149.32	***
Breusch-Pagan test	0.03		6.89		9.68	
Ramsey RESET test	0.37		0.03		0.29	
Mean VIF	2.57		2.73		3.58	
Observed Moran's *I*	0.151	***	0.142	***	-0.037	

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

3.4.3.2 Dealing with spatial autocorrelation of residuals

The possible bias caused by the spatial autocorrelation of residuals represents another problem in the empirical analysis. This happens because the units of analysis are territorial entities, close to one another, which could show similar behaviour on the basis of geographical proximity. If regression residuals are spatially auto-correlated, then OLS estimates are biased. More specifically, bias could affect the consistency or the efficiency of the estimates on the basis of the spatial model that generates data. Spatial autocorrelation of residuals can be due to a spatial dependence mechanism or to an unobserved spatial heterogeneity of coefficients. In other words, before interpreting the residuals' spatial autocorrelations in terms of spatial dependence (e.g. spillovers of productivity between regions, or spatial diffusion of economic shocks from one given region to a neighbouring region) any potential spatial heterogeneity needs to be removed from the model. For this reason, two regional dummies (*d_north*, *d_centre*) were included in the model, given that Italian economic development is strongly differentiated between the north, south and centre of the country. Even including the two macro-regional dummies, Moran's *I* statistic does not allow for the hypothesis that residuals are not spatially correlated for both OLS and 2SLS estimations (Models 1-2, Table 3.2). In order to deal with this problem and to get consistent estimates, a spatial lag model was estimated using instrumental variables (S2SLS), after looking at the results of a robust LM test of spatial autocorrelation. The spatial lag model includes the spatial lag[26] of the dependent variable, which was instrumented with the spatial lag of the regressors, as suggested by Kelejian and Prucha (1998). The choice of a S2SLS is also consistent with spatial auto-correlated shocks and can at the same time deal with the potential endogeneity of spatial structure variables.

3.4.3.3 Interpreting results

The results of the empirical analysis carried out on the basis of the theoretical model discussed in Section 3.3 are presented in Table 3.4. For all the estimated models, White's standard errors were used. OLS estimations are robust for using different estimation strategies that were adopted in order to deal with endogeneity of regressors or spatial autocorrelation of residuals. Signs of estimated coefficients do not change and magnitudes present only small differences. Coefficients relative to all the traditional regressors show the expected sign. In fact, the control for capital-labour ratio is positive, as well as the controls relative to land-labour ratio and to the share of graduates. The two latter variables, however, are not statistically different from zero, which is consistent with the results obtained by Meijers and Burger (2010). The non significant role of high-level education for economic performance is not a new finding in the Italian case (Cirilli and Veneri, 2011; Pietrobelli, 1998). These results have different explanations, from the sectorial composition of the Italian economic system to the weakness of university graduates as a measure of human capital, and similar results have also been found for other countries (Cheshire and Magrini, 2006).

Regional dummies are also statistically significant and show the expected sign, since the reference region – the south of Italy – is thought to be the economically weakest region in the country, followed by central Italy. Regarding the spatial lag of the dependent variable (Wy in Model 3), it proved to be positive and significant, with a very high elasticity (35.5%). This means that if a region has a high level of productivity, its neighbours strongly benefit in their productivity levels thanks to physical proximity. Regarding sectorial specialization, results show that more diversified economies perform better, while the specialization on the FIRE industries turns out to be positive, as expected, but statistically not significant.

Turning to the spatial structure variables, which represent the main focus of this work, results show that all the three dimensions of spatial structure – size, polycentricity and centralization – significantly affect the productivity levels of the Italian NUTS-3 regions. Regional size accounts for the intensity of urbanization externalities and, in agreement with most of the literature, it has a positive and significant impact on labour productivity. The elasticity of size with respect to productivity is 3.6% (Model 3), as confirmed by Rosenthal and Strange (2004), who reported an elasticity range from 3% to 8%.

---

[26] In order to compute spatial lags, different weight matrixes were used, based on distance thresholds, contiguity and *k*-nearest neighbourhood. Results are robust for using of all kinds of spatial weights. Tables and tests are reported here using four-nearest neighbours matrices.

As far as centralization is concerned, results show that more centralized regions are associated with a higher productivity. By doubling the centralization of activities, labour productivity increases by 2.7%. This confirms the hypothesis that a more centralized pattern in the spatial distribution of activities leads to higher agglomeration economies and, as a consequence, to higher economic performance.

The degree of regional polycentricity was negatively associated with productivity levels, which is consistent with Vandermotten et al. (2007). This result does not confirm the hypothesis that, at least with regard to NUTS-3, agglomeration economies have regionalized. Hence, the mechanism of “borrowing size” with which polycentric structures can take the place of a single large agglomeration (monocentric structure) does not occur within regions. A negative association between polycentricity and economic performances has also been found by Lee and Gordon (2007), but without a strong statistical significance.

As argued by Lee and Gordon (2007), the growth effects of spatial structure can be dependent on metropolitan size. The final part of our analysis investigates the role of size, polycentricity and centralization for small and large regions. Table 3.4 reports signs and significance of coefficients estimated using OLS with robust standard errors, where regions have been divided into two groups according to their size: small regions are those with a population less than 350,000 inhabitants in 2001, while large regions are those with a population higher than 350,000.

Given the limited number of observations in each group and the possible limitations in the reliability of the estimations, it is worth focusing on the coefficient signs and on their statistical significance. The results in Table 3.4 show that, although there is a decrease in most of the significance of the coefficients, the signs of spatial structure variables are always consistent with those found using the whole set of statistical units (Table 3.3). The statistical significance of the total population coefficient is higher for the group of large regions. This suggests that the overall strength of agglomeration forces has a significant effect on small and medium-sized regions, while the same effect decreases in particularly large regions, where agglomeration diseconomies may arise.

Table 3.4: Estimation results. Dependent variable: *lab_productivity*. Estimations for regions of different size classes.

Robust standard errors are reported in brackets.

	Small regions		Large regions	
intercept	-3.960	(0.548)***	-2.137	(0.366)***
k_lab_ratio	0.121	(0.066)*	0.307	(0.064)***
land_lab_ratio	0.015	(0.013)	-0.019	(0.015)
graduates	-.0810	(0.085)	0.094	(0.077)
d_north	0.069	(0.044)	0.150	(0.037)***
d_centre	-0.002	(0.032)	0.076	(0.029)**
hhi	-0.005	(0.052)	-0.118	(0.061)*
fire	0.082	(0.061)	0.056	(0.065)
size	0.080	(0.036)*	0.002	(0.025)
polycentricity	-0.031	(0.024)	-0.031	(0.031)
centralization	0.043	(0.023)*	0.008	(0.007)
N. observation	47		56	
Squared R	0.408		0.680	

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

3.5 Concluding Remarks

The aim of this chapter was to contribute to the debate on the effects of spatial structure on the economic performances of regions. Our particular focus was on the measurement of spatial structure characteristics, since size and density, taken alone, cannot detail exactly how regions are spatially organized. From the empirical analysis it emerged that spatial structure does play a role in explaining the differences in the levels of productivity.

Four key results were found. First, productivity increases with size, hence confirming the hypothesis that urbanization externalities have a positive and significant effect on labour productivity, and the elasticity is consistent with what has been already found in the literature.

Second, the extent to which activities are centralized in the main urban node has a positive and significant impact on productivity. This means that pure physical proximity is important for economic performance, since it is directly related to the generation of agglomeration externalities. Hence, dispersed regions perform worse than compact and centralized regions, highlighting, from a policy perspective, a possible negative economic effect of sprawl.

Third, the degree of polycentricity does not have a positive impact on economic performance. This means that, at least in the sample of Italian NUTS-3 regions considered in this analysis, relational proximity between different centres cannot be a substitute for physical proximity in monocentric regions. Hence, despite the fact that cities and metropolitan areas are now a regional phenomenon, monocentric regions are still stronger in terms of agglomeration externalities.

Finally, the effect of the overall strength of agglomeration forces seems to change on the basis of the size of the regions that were included in the analysis. In fact, size always has a positive impact on productivity. However the magnitude and the significance of the related coefficient is higher for small regions and then decreases for larger regions. The productivity of small-sized regions has previously been thought to be positively affected by polycentric structures, in order to compensate for a smaller size, but this effect was not empirically verified in our study.

Therefore, an optimal spatial structure may not be easily identifiable, since several efficient structures can exist on the basis of the size and on other relevant characteristics of the regions. For example, sectorial composition may play an important role in understanding which spatial structures are more efficient. In fact, although sectorial composition was considered in this analysis, a more thorough study by sector might be useful, since some sectors may only benefit from physical proximity while others may take advantage of relational and functional relations at a regional level. These issues represent promising questions for further research on this topic.

3.6 APPENDIX: Spatial structure and economic performance in Italian Functional Urban Regions

This appendix analyse the effect of polycentricity and dispersion on employment growth in Italian Functional Urban regions.

3.6.1 Urban Dispersion and Polycentricity

The extent to which economic activities are centralized or dispersed can be quantified in several ways (Galster et al., 2001; Lee, 2007). In this work two indicators have been applied. The first is the ratio between the jobs located in the main centre[27] and the total regional employment (*PJ*):

$$PJ = e_{CBD}/E \tag{31}$$

where e_{CBD} is the employment within the CBD (the central municipality) and E is the total employment of the urban region. *PJ* represents a basic and straightforward measure for centralization (dispersion), providing information about the role of the main centre in terms of employment. The higher the value, the higher the centralization of the FUR.

The second indicator of dispersion (centralization) is the weighted average distance from the CBD, or *ADC* indicator (Galster et al., 2001), which is computed as follows:

$$ADC = \sum_{i=1}^{n} \left({e_i}/{E} \right) * DCBD_i \tag{32}$$

where e_i is the number of jobs in the *i*-th municipality and $DCBD_i$ is the distance from the centre of the *i*-th municipality to the centre of the CBD. The higher the *ADC*, the more dispersed the region. In comparison with PJ, this indicator weights the centralization with a pure morphological element, the distance from the CBD, hence it is less affected by the possible differences in the administrative boundaries of single municipalities.

Both indicators have an implicit assumption: the existence of one centre (the central

[27] By main centre or pivot centre we refer to the largest municipality in terms of population.

business district, or pivot municipality). Thus, they suppose a monocentric structure. This can be a limitation, since many FURs are actually polycentric. However, these indicators are able to take into account the physical distribution of activities within the whole territory of the FURs, taking into account elements like the physical distance that separate, on average the localization of the employment. In addition, the extent to which FURs are polycentric is effectively measured with apposite indicators proposed in the sub-section below.

As already mentioned, polycentricity relates to the number of centres within a region. There are two approaches to the conceptualization of monocentricity-polycentricity: the morphological and the functional. In both cases, polycentric regions are those characterised by the coexistence of two or more urban centres. According to the morphological approach, the centres should be not too dissimilar in terms of size and the region should be characterised by flat hierarchy. Instead, the functional approach focuses on the distribution of functions and on the interactions between urban centres (Green, 2007), where interaction is quantified by measuring flows – mainly daily commuting flows. As a consequence, the two approaches differentiate in the measures to be taken into account (Burger and Meijers, 2011).

Regarding the morphological approach to polycentricity, the main indicator is represented by the estimated OLS coefficient (β) of a rank-size equation (Parr, 2004). The lower the (absolute) value of β, the flatter the hierarchy among centres, hence the higher the level of polycentricity.

Functional polycentricity has been measured by using the Special Functional Polycentricity (P_{SF}) (2007, p. 2084-2087). This indicator starts from the idea that each FUR is a network of municipalities connected through commuting flows. In this context, polycentricity is defined on the basis of the relationships that take place within the network.

The two proposed dichotomies to analyse spatial structure may not be perfectly independent. Correlation between the indicators of monocentricity-polycentricity and centralization-dispersion show that, on average, more polycentric FURs are also more dispersed (Table 3.5). In addition, the overall size of regions can be conceptualized as a third fundamental dimension of spatial structure, perhaps even more important than the others. For the sake of simplicity, all the indicators used for correlations in table 3.5 were defined in terms of jobs, while in the regression analysis carried out afterwards, both jobs and population-based indicators were used separately. Regional size is here approximated with the total number of jobs in the last available Census (2001).

Table 3.5: Pearson correlation coefficients among indicators of spatial structure

	PJ	PSF	ADC	Size
PJ	1			
PSF	-0.57	1		
ADC	-0.49	0.21	1	
Size (empl.)*	-0.18	0.41	0.50	1

* Size (empl.) is total number of Jobs in the private sector in 1991

Source: elaborations on data from Istat

Consistently with expectations, dispersion increases as size increases. Functional polycentricity is also positively correlated with size, consistently with the theory that sub-centres in the urban region increase with population (Fujita and Ogawa, 1982; Mc Millen and Smith, 2003). On the other hand, morphological polycentricity decreases with size: thus larger FURs are characterised by a higher role of the main centre within the functional region, hence by a steeper hierarchy among centres.

3.6.2 **Model specification, methodology and data**

3.6.2.1 Units of analysis

Fundamental to the understanding of the spatial scope of agglomeration externalities and their possible regionalization is the definition of the spatial boundaries of the urban regions. When studying the outcomes of spatial structure, the choice of the unit of analysis is crucial. The serious discrepancy between the administrative structure – not significantly updated since the early 20th Century – and the functional organization of the territory has been already documented in Italy (Calafati and Veneri, 2011). A definition of functional economic area appears much more appropriate to understand the processes that take place in a given territory and to inform appropriate policies for their development.

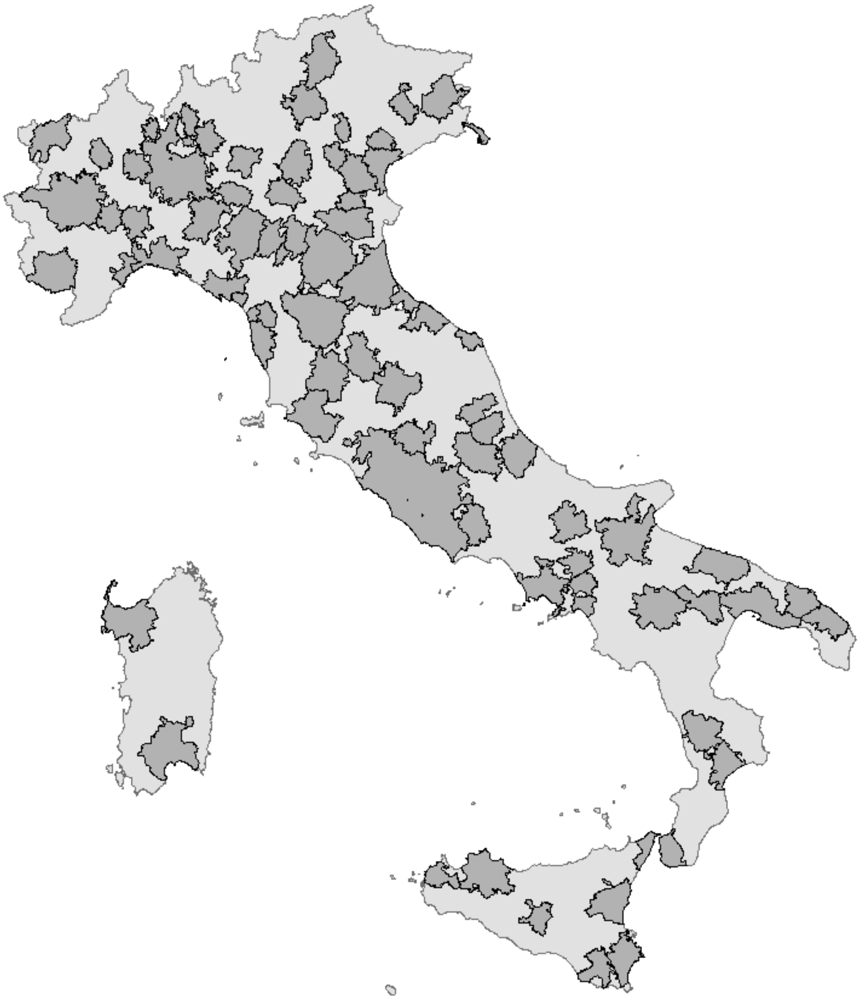


Figure 3.5: The Italian Functional Urban Regions

On the background of the several definitions of functional areas, this appendix adopts the notion of Functional Urban Region (FUR) as unit of analysis (Hall and Hay, 1980; Cheshire and Hay, 1989). FURs represent areas of interactions between one or more cores and its/their hinterland of neighbour municipalities, which show significant functional relationships with the core. Such relationships are usually taken into account by using daily commuting flows. Thus, FURs represent economic regions and appear to be the most suitable units of analysis to investigate the effect of spatial distribution of activity on the performance of urban areas (OECD, 2012). In this work 81 Italian FURs are considered, as identified by Boix and Veneri (2009)[28] and represented in Figure 3.5.

[28] The methodology of identification of FURs comprises two steps: first, the cores of each FUR are identified (they should be composed by at least 20.000 jobs, with a density at least 7 jobs per hectare). Then, all contiguous municipalities accounting at least 10% of commuting towards the cores are merged.

3.6.2.2 Data and methodology

This section introduces the econometric specification to empirically investigate how spatial structure affects the economic performance of Italian FURs. The model specification mainly relies on the literature of urban growth, where the change in population or employment is a function of a set of factors (Glaeser et al., 1992; 1995; Glaeser and Shapiro, 2003). Under the hypotheses to be tested in this work, the economic performances of functional urban regions can be affected by their characteristics of spatial structure thanks to a better exploitation of agglomeration economies. Agglomeration is conceptualized as a source of increasing returns and explains the growth of cities beyond the level of their steady state (Rosenthal and Strange, 2004). The general model specification to be adopted is hence the following:

$$Log\frac{Y_{t+1}}{Y_t} = \alpha + \beta_1 \log(Y_t) + \beta_2 \log(disp_t) + \beta_3 \log(polyc_t) + \sum_j \beta_{j+4} \log(X_j) + \varepsilon \qquad (33)$$

where Y_t is the vector of population (or jobs) in the FURs at time *t*. It represents the first element of spatial structure, the size. In addition to this, $disp_t$ is the index of dispersion and $polyc_t$ is the index of polycentricity. Following the literature concerning growth in cities, we included a set of control variables X_j. Demographic structure has been captured by the share of people aged over 65 (Blumenthal et al., 2009). The percentage of graduates over total population older than 25 reflects human capital (Cheshire and Magrini, 2006; Cirilli and Veneri, 2011). Following Lee and Gordon (2007), the share of jobs in manufacture over total employment has been added as a control for the industrial mix. Finally, the unemployment rate controls for socioeconomic conditions and, at least partially, for spatial heterogeneity. Table 3.6 lists the variables and provides some descriptive statistics.

Table 3.6: Descriptive statistics for the variables used in the analysis

Variable	Description	Mean	Std. Dev.	Min	Max
growth_pop	growth rate of population between 1991 and 2001	0.01	0.04	-0.08	0.09
growth_job	growth rate of employment in the private sector between (1991-2001)	0.05	0.08	-0.19	0.25
pop	total population in 1991	12.52	0.87	11.20	15.47
over65	share of people older than 65 in 1991	-1.84	0.21	-2.36	-1.44
graduates	share of people with tertiary education and higher in 1991	-3.29	0.26	-4.25	-2.81
loc_man	share of employment in manufacturing activities in 1991	-0.16	0.36	-0.95	0.54
unempl	unemployment rate in 1991	-2.03	0.64	-3.11	-0.85
psf	special functional polycentricity (Green, 2007) in 1991	-1.89	0.71	-4.98	-0.76
beta	average value of rank-size coefficients with 2,3 and 4 centres (1991)	0.71	0.36	-0.89	1.27
adc	average distance from the CBD weighted by population (1991)	1.81	0.39	1.04	3.11
pj	share of jobs in the pivot municipality over total employment in the FUR (1991)	-0.62	0.24	-1.40	-0.18

Source: elaborations on Istat data (1991, 2001). All the variables are expressed in logs.

A possible problem arising from the estimation is the potential endogeneity of spatial structure variables (Graham et al., 2010). In principle, simultaneity between growth of cities and their spatial structure could be in place, since growth in cities could affect the way in which activities are organized throughout space. However, the characteristics of spatial structure change only slowly and should not be much affected by growth processes in the short run (Meijers and Burger, 2010).

A second problem is the potential spatial dependence of errors. Since units of analysis are urban areas that are sometimes close to one another, spatial dependence, if present, could introduce biases in the estimation of coefficients in a simple linear model. More specifically, OLS estimation are inconsistent if the true process generating data is a spatial lag, hence if growth in a specific area affects the growth of its neighbours (spillover effect). On the other hand, OLS estimation are inefficient if a random shock affecting a specific region has effects in neighbouring regions, hence if the true process generating data is a spatial error.

In order to check if spatial dependence affected the model's residuals, a Moran's I test was performed, by using different types of spatial matrixes. The null hypothesis of absence of spatial autocorrelation can never be rejected; hence the linear model is not biased and can be adopted correctly to estimate the growth equation.

Urban performance has been measured in terms of variation rates of both population and employment between 1991-2001. Employment data is referred to the private sector only.

There are several reasons behind the choice of these dependent variables. First, cities, more than regions and countries, are very open economies that have access to mobile production factors – e.g. capital and labour – from a shared pool (Glaeser et al., 1995). Given this high degree of openness, the focus on movements of labour and population can be more appropriate than looking at variation in the output of urban areas. A second reason is that, given the functional nature of the units of analysis, data about value added, as well as other measure of output, are not available from the official statistical institutions. Third, employment and population, at least in the medium term, reflect the variation in productivity and in the quality of life, where population has a higher connection with the latter. From Table 3.6 it emerges that variation rates in terms of employment are on average higher, and with a higher variability, than those related to population. On the whole, it appears that the performance of FURs in Italy is very heterogeneous, showing both high-growing and high-declining cities.

3.6.3 **Main results**

This section reports the results of regression analysis. The latter has been carried out through the estimation of OLS with robust standard errors. For each type of dependent variable – variation rates of population or employment – two different specifications are estimated. This is because the centralization of FURs has been measured with two different indicators (*PJ* and *ADC*), for reasons of robustness.

Table 3.7 reports the estimation results when urban performance is measured in terms of employment growth. Results show that the variables associated with human capital and with the share of manufacture are not significant. Regarding the share of graduates, the sign is always negative. Similar evidence was found also in other works on Italy (Cirilli and Veneri, 2011) and on other countries (Cheshire and Magrini, 2006). Among the possible reasons are the weakness of education level as a measure of human capital and the sectorial composition prevailing in Italy. In fact, human capital is accumulated also through fundamental processes of learning by doing, which are not taken into account with the share of graduates. In addition, the relatively high sectoral specialization of the Italian economy in traditional manufacturing sectors, often characterised by high-intensity of labour and low skills, can also play a role.

Among the control factors with the highest explanatory power are the demographic composition of the local population and the initial unemployment rate, which in turn reflects the general socio-economic conditions within each FUR. More specifically, results show that an older population is associated with a lower growth both in terms of population and employment (Canton et al., 2002). Higher unemployment rates are also associated with lower growth rates, suggesting that economies that were weaker at the beginning of the period tended to remain weak.

As far as the variables of spatial structure are concerned, it emerges that size has a negative coefficient, even if not always statistically significant. Behind the negative association between size and growth there could be a process of (slow) catching up from lower-sized FURs, as well as the emergence of congestion effects in the largest areas.

Regarding the dichotomy polycentricity-monocentricity, it turns out that monocentric structures are associated with higher growth rates. The coefficient associated to the degree of polycentricity is not significant in one case, but it always maintains the negative sign. On average, for the sample of Italian FURs that has been considered in this work, a spatial structure where the bulk of the flows is concentrated in a single or few centres performs better than structures characterized by a higher number of centres. In other words, when considering a centre as a place that organizes the territory in functional terms – approximated by the capacity to attract commuting flows – agglomeration externalities can be better exploited at the level of centre, hence monocentric structures are associated with higher exploitation of such externalities.

Table 3.7: Estimation results. Job and population growth 1991-2001

	(a) Job growth		(b) Job growth		(c) Pop growth		(d) Pop growth	
intercept	-0.213		-0.096		-0.16	**	-0.18	**
	(0.23)		(0.27)		(0.08)		(0.08)	
pop	-0.013		-0.029	*	-0.01	**	-0.01	
	(0.01)		(0.02)		(0.00)		(0.01)	
over65	-0.172	***	-0.207	***	-0.14	***	-0.15	***
	(0.05)		(0.04)		(0.02)		(0.02)	
graduates	0.049		0.053		0.03	**	0.03	**
	(0.04)		(0.04)		(0.01)		(0.01)	
loc_man	-0.019		0.009		0.00		0.00	
	(0.03)		(0.04)		(0.01)		(0.01)	
unempl	-0.066	***	-0.070	***	-0.04	***	-0.04	***
	(0.02)		(0.02)		(0.01)		(0.01)	
psf	-0.034	**	-0.024		-0.01	**	-0.01	*
	(0.02)		(0.01)		(0.00)		(0.00)	
pj	-0.117	**			-0.03	*		
	(0.04)				(0.01)			
adc			0.064	**			0.00	
			(0.03)				(0.01)	
n.obs.	81		81		81		81	
F(7, 73)	6.3		4.6		18.33		18.41	
Prob>F	0.000		0.000		0.000		0.000	
Sq. R	0.32		0.31		0.52		0.50	
av. VIF	2.08		2.15		2.08		2.15	

* significant at 5% level; ** significant at 1% level

Table 3.8: Estimation results with interactions. Jobs and pop. growth 1991-2001

	(a) Job growth		(b) Job growth		(c) Pop growth		(d) Pop growth	
intercept	-1.923	***	-0.553		-0.120		-0.286	
	(0.71)		(0.96)		0.217		0.275	
pop	0.133	**	0.010		-0.012		0.001	
	(0.06)		(0.07)		0.017		0.022	
over65	-0.128	***	-0.192	***	-0.145	***	-0.149	***
	(0.05)		(0.04)		0.018		0.018	
graduates	0.056		0.053	**	0.034	**	0.029	**
	(0.03)		(0.04)		0.014		0.014	
loc_man	-0.036		0.000		-0.002		0.003	
	(0.03)		(0.04)		0.011		0.011	
unempl	-0.060	***	-0.069	***	-0.043	***	-0.045	***
	(0.02)		(0.02)		0.007		0.007	
psf	-0.718	**	-0.389		0.020		0.001	
	(0.27)		(0.25)		0.085		0.065	
pj	-1.313	**			-0.045			
	(0.56)				0.160			
adc			0.027				0.057	
			(0.35)				0.096	
size_psf	0.056	**	0.030		-0.003		-0.001	
	(0.02)		(0.02)		0.007		0.005	
size_pj	0.094	**			0.001			
	(0.04)				0.012			
size_adc			0.003				-0.005	
			(0.03)				0.008	
n. obs.	81		81		81		81	
F(9,71)	6.03		4.51		15.3		15.05	
Prob > F	0.000		0.000		0		0	
R-squared	0.39		0.35		0.52		0.5	
VIF	198.27		158.81		198.27		158.81	

* significant at 5% level; ** significant at 1% level

Regarding the physical organization of activities in terms of centralization-dispersion, it turns out that FURs where activities have a higher level of dispersion throughout the region are associated with higher growth rates. This result is confirmed in both the model specifications for the employment growth. These results are consistent with the idea that, within functional regions, a higher physical dispersion does not preclude the exploitation of agglomeration economies. Rather, a higher dispersion is associated with lower congestion, hence with higher growth.

When population growth is used as dependent variable, the effects of size turn out to be higher. This is consistent with the idea that congestion costs play a role for quality of life, affecting the demand side of the economy. Thus, *ceteris paribus*, population grows at lower rates in the largest metropolitan areas, where congestion costs are higher. Polycentricity and compactness turn out to be negatively associated with population growth, consistently with the results found for employment growth. However, when centralization is measured with the ADC index, the coefficient is not different from zero.

Regarding the role of human capital, estimations show that the coefficient associated to the level of education is positive, consistently with previous results and also statistically significant. Behind the higher significance of the coefficient related to education when population growth is taken into account can be the increase in low-skilled jobs, for which tertiary education is less important.

The efficiency of spatial structure can be dependent on the size of functional regions. This means that a polycentric structure may be desirable in large FUR, while a monocentric structure in a small or medium sized FUR, or vice versa. In order to grasp some of this relationship, the same model introduced above were estimated including the interaction variables between size and polycentricity and between size and centralization. Estimation results are showed in table 4. Such results confirm the sign of coefficients for polycentricity and centralization that were estimated in the previous models. In fact, monocentric and dispersed areas were associated with higher growth rates. However, the significance of all coefficients decreases severely and problems of multi-collinearity are more than likely to affect the interpretation of the results – the VIF statistics is well above 10.

Focusing on the sign of the estimated coefficients, it turns out that the positive effect of a monocentric structure decreases with size. Thus, as soon as large FURs are considered, monocentric structures are less efficient and polycentricity can represent a more efficient spatial organization of activities. The interaction of size with centralization is to some respects similar to that with polycentricity. In fact, the negative association between population growth rates and centralization decreases with size. Hence, for large metropolitan areas the physical proximity among agents turns out to be more important than for small and medium sized FURs.

3.6.4 **Concluding remarks**

The aim of this appendix was to contribute to the debate on the role of spatial structure for economic performance of functional urban regions. The major contribution is the empirical investigation on a topic that is much debated in the European policy discourse, but that is much less discussed in terms of both economic theory and empirical analysis. In addition, the conceptualization and measurement of spatial structure is in many cases limited to basic dimensions such as size or density and the coherence of the units of analysis is not always taken into account properly.

The measurement of spatial structure was provided by first distinguishing two key elements – polycentricity and centralization – that are at a first glance very similar, but that are related with different dimensions. These two elements are related with a functional and morphological dimension, respectively. Currently, the debate on polycentric city regions should take into account the functional organization of regions more than their physical structure. In fact, behind the increasing flattening of the density gradients within functional regions often there are increasingly strong functional hierarchies.[29]

The relevance of spatial structure for economic performance is framed in the theory of agglomeration externalities, under the hypothesis that the regionalization of cities in wider functional urban regions has been followed by a regionalization of the increasing returns coming from agglomeration. In this respect, the identification of appropriate units of analysis is central to investigate the characteristics of spatial structure and their implications. This work provided a definition of functional urban region whose boundaries are not constrained by administrative settings and reflect the actual spatial dimension of regional economic processes.

The analysis highlights that spatial structure characteristics, as they are conceptualized in this investigation, are associate to different economic performance of Italian FURs. On the whole, the hypothesis under which regions characterized by several small centres in dense relationship can substitute the benefits of a single strong agglomeration is not supported by the analysis. Hence, monocentric regions grow more and this association is higher for smaller regions. On the other hand, physical dispersion of people and employment across the territory is also associated with higher growth. Congestion costs and a decreasing importance of a purely physical proximity among agents within a same functional region may have an important role in explaining this result.

Spatial structures change as they adapt so as to find the right trade-off between economies and diseconomies of agglomeration. Certainly the end result will also depend on economic and functional characteristics of cities, from their sectoral specialization to their rank. The spatial structures are therefore the result of a process that self-organizes to achieve more efficient structure – economies vs. diseconomies of agglomeration –, but also the result of slow and path dependent processes (including processes of coalescence of old and previously independent centres).

Identifying what actually are the benefits of polycentric areas can help policy makers to question the normative aspects related to the concept of polycentricity and to eventually help understanding the possible implication of different patterns of development of the territory. However, in order to influence the evolution of urban structure a long-run perspective is necessary, since in the short run only marginal changes are possible (Batty, 2001). In this respect, an analysis of the evolution of spatial structure in the long term and their – possible changing – implication can represent a natural step forward in this research.

[29] This statement was proposed and discussed during a round-table on polycentric regions at the Annual Conference of the Regional Studies Association, held in Delft (NL) in May 2012.

4 Urban spatial structure and environmental emissions: a survey of the literature and some empirical evidence for Italian NUTS-3 regions

Abstract
This chapter addresses the relationship between urban spatial structure and emissions. By surveying the most relevant literature, first we discuss the concept of spatial structure, focusing in particular on polycentricity and dispersion, and then we summarise the possible links between spatial structure and emissions. The survey provides the framework to explore the empirical evidence for Italy concerning CO_2 and PMs emissions originating from private transport and house heating. Results suggest that spatial structure affects CO_2 emissions from private transport and PMs from housing emissions. There is no evidence for polycentricity to reduce emissions.

4.1 Aims

Environmental crises often occurred also in the ancient world, concerning not only resource management (e.g. the well-known and widely studied case of Easter Island) but also pollution. For instance, more than 2000 years ago, purple production had strong impacts in the Phoenician city of Tyre, as attested by Strabo who wrote "the great number of dye-works makes the city unpleasant to live in, yet it makes the city rich" (Strabo 16,2,23, in Jones, 1930, p. 269). The novelty that emerged with the industrial revolution was the huge progress in the ability to exploit fossil fuels. This gave humans the power to move and process huge amounts of matter (e.g. Matthews and Hutter 2000), greatly increasing not only their prosperity but also their environmental impacts. In other words, energy abundance radically changed the relationship between us and our environment, involving increases not only in the intensity of human pressures and impacts but also in their spatial scope. The relevance of the phenomenon is such that a new discipline, land-change science, emerged to study the causes and consequences of land use and land cover change, the contribution of which, for instance, is highly relevant (33% of total emissions in the period 1850-1990) in the carbon budget (e.g., Houghton, et al. 2012).

Energy has determined also urban development. Actually, in the Neolithic the improvements in agriculture and in stock breeding resulted in energy surpluses that made possible for a larger share of the population not to be committed to food raising, which involved the emergence of the city (e.g., Glaeser 2011, p. 168, and Mumford, 1956). Again, with the radical change in energy availability, industrial revolution involved a rapid growth of urbanization, due both to population growth and to migration from the countryside, a process that is still occurring in emerging countries.

Again, energy is a major factor for structural changes occurring in urban areas in the last decades (Anderson et al., 1996, 12), since “cheap” energy made transports quicker, cheaper and more comfortable, making it easier to reside away from urban cores. As a result, we got urban sprawl so that “the contemporary city has no clear boundaries; its a city of dissipated activities and changeable links” (Bertolini, 2012, p. 18). Urban sprawl makes evident the links between energy abundance, spatial organization of human settlement, and environmental pressures, both at local and global level. For instance, Bart (2010) analysed the relationship between trends in transport emissions and urban land-use, founding a strong correlation between transport CO_2 emissions and the increase of artificial land area.

The present investigation aims to explore the role of spatial structure, focusing on private transport and residential energy consumption and the involved CO_2 and PM_s emissions in the Italian case. Firstly (section 4.2), by surveying the most relevant literature, we set the theoretical frame and illustrate the current empirical evidence. Then (in sections 4.3 and 4.4) we move to empirical analysis to test whether the theoretical intuitions hold for Italy, analysing its provinces (NUTS-3 spatial level).

Italy provides an interesting case study, since, like other advanced countries, showed pronounced phenomena of urbanization and suburbanization. Actually, in the 1950s urbanized areas covered 8700 km^2 (178 m^2 per capita) while in 2012 they covered 21900 km^2 (370 m^2 per capita) (ISPRA, 2014). Moreover, like in other European countries (Anas et al., 1998), Italian urban evolution is path dependent, that is, urban areas and conurbations emerged from the coalescence of previous existing centres (Calafati, 2012).

4.2 Spatial structure and the environment

This section provides an overview of the theoretical and empirical state of the art on the relationships between spatial structure and environmental pressures. First, we focus on definitions and measurements of spatial structure, and then we move on the possible causal links between spatial structure and emissions.

4.2.1 Definitions of spatial structure

The concept of spatial structure refers to "an abstract or generalized description of the distribution of phenomena in geographic space" (Horton and Reynolds 1971, 36). From an economic point of view, those phenomena refer to the economic activities of firms and households - namely residential and productive activities - across space. The city is the environment in which those activities develop and influence each other. As highlighted in the literature (for instance by Lee, 2006, p. 9) urban spatial structure is the resultant of the distribution of people and economic activity across space, which is in turn the outcome of long-term processes involving locational preferences of agents and public policies. The distribution of economic activities, which is sometimes called "urban form" (Anderson et al., 1996), is related to urban interactions: urban form and interactions together give rise to spatial structure (Bourne, 1982).

The centres are the key elements in the regional structure and development. Being characterized by concentration of economic activity, the centres represent the economic core of spatial systems, providing functions to the rest of the region. Urbanization has promoted agglomeration economies (Glaeser et al. 1992) and cities represent the engines of economic growth for regions and countries. By means of several mechanisms, urban environments promote economic advantages for firms and households, which may result in higher productivity, income and quality of life (Glaeser, 2011).

Actually, the dynamics of human settlements, both in history and space, can usefully be described by referring to the changing roles of the centres and of the territory around them. In some instances regions are organised around a main centre, in other we observed several interconnected centres, while the urbanization degree and patterns around centres may considerably differ (Camagni et al., 2002). Although we acknowledge the multi-faceted nature of the concept of spatial structure, we will follow here Meijers and Burger (2010) by focusing only on urban dispersion and polycentricity, two concepts that, despite their interrelationships (Gordon and Wong, 1985, 662), need to be kept distinct.

4.2.1.1 Urban dispersion

Urban dispersion refers to the extent to which economic activities are spatially concentrated in centres or, conversely, evenly dispersed. Hypothetically, we have two polar cases depending on where most of human activity is settled, either concentrated in one (or more) centre or diffused homogeneously across the region. Recent dynamics in rich countries has often moved regional structure towards dispersion rather than concentration, generating the so-called "urban sprawl".

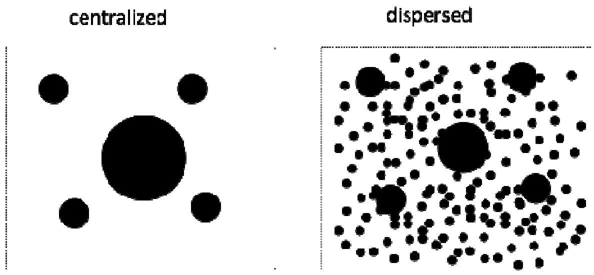


Figure 4.1 Centralized and dispersed regions

The increase in urban dispersion became relevant in North America already in the first half of 20th century due to the revolution involved by mass motorization (Burchfield et al, 1998). Commuting became cheaper and easier allowing more freedom in the choice of the residential location. People did not anymore need to live close to their workplace or commercial activities and started to relocate out from city cores. Residential relocation firstly involved upper income classes, who initially could afford the use of private vehicles, then, due to the decline in transport costs, also low income households attracted by the cheaper land prices of the surroundings (Le Roy and Sonstelie, 1983). The cheap land prices also made the new settlements to be characterized by extensive land use. Similar dynamics appeared later on in Europe and other areas, where urban growth came together with urban sprawl in the last decades, in particular in the most advanced regions and in areas characterized by rapid economic growth (European Environment Agency - EEA, 2006).

A comprehensive understanding of urban dispersion requires acknowledging its multidimensionality, involving several interconnected aspects and driving forces such as economic development, technological progress, change in preferences, regulatory framework, geography and climate, and others (EEA, 2006, 17). Actually, urban sprawl has been approached by different disciplines and points of view (Frenkel and Ashkenazi, 2008; Arribas-Bel et al., 2010) resulting in a large amount of literature. As a consequence, there is no widely accepted definition and measure for it (Galster et al., 2001; Chin, 2002). However, the commonly shared idea is that urban sprawl relates to patterns of "excessive" geographical expansion of urban settlements (Brueckner, 2000), involving a sub-optimal utilisation of land. In static terms, this means that the distribution of economic activities across space is mainly characterized by extensive land use.

A commonly used indicator for urban sprawl is gross residential density, that is, the number of residents (or residential units) per unit of land (e.g. Travisi et al. 2010). This, however, does not allow for comparability across regions with different geographic features and planning policies. For this reason, as suggested among others by Galster et al. (2001), net density is a better indicator, that is density calculated with respect to the land that can be used, the so-called developable land[30]. We proxy developable land with land actually used for artificial purposes as provided by remote-sensing data (Burchfield et al., 2006).

4.2.1.2 Polycentricity

Polycentricity refers to balanced hierarchical relationships among centres in a regional system, occurring when most of economic activity is evenly distributed across centres of comparable size, rather than concentrated in a main centre. Polycentricity is not necessarily a legacy of the past; it can also emerge from monocentric regions when their sub-centres increase their relative relevance as compared with the main centre.

There are many approaches to define and measure polycentricity within urban regions (Meijers and Burger, 2010). A first one considers morphological aspects, while a second one takes into account functional relationships within centres. Morphological polycentricity considers hierarchy mostly in terms of size-distribution of centres (Parr, 2004), while the functional approach conceptualizes hierarchy in terms of interactions among centres (Green, 2007).

One of the most widely used measures of morphological polycentricity is represented by the coefficient of the rank-size estimation:

$$ln(r) = \alpha + \beta\ ln(s) \tag{34}$$

where *r* represents the rank of the i^{th} city within the region, measured in terms of population, while *s* represent the size (population). The absolute value of *β* indicates the level of morphological polycentricity, the higher the value, the higher the polycentricity of the urban region. Rank-size estimations have been widely used in the literature, especially in works concerning the Zipf's Law for cities, i.e. the empirical regularity that city-size distribution follows a power law[31].

Functional polycentricity is measured by indexes derived by network analysis. Here we will use the Special Functional Polycentricity Index, P_{SF} , proposed by Green (2007), which combines both the spatial distribution of centres and the density of functional relations that take place within a region.

P_{SF} is computed as follows:

[30]"Land that has no natural features, public uses, or regulatory barriers to its development at urban densities—is a better denominator for calculating density than total land area. It is also a more useful area for measuring all the other dimensions of land use patterns" (Galster et al., 2001, 688).

[31] For a recent survey and empirical analysis on ZIpf's law for cities see, e.g., Veneri (2013).

$$P_{SF} = \left(1 - \frac{\sigma}{\sigma_{max}}\right)\Delta \qquad (35)$$

where σ is the standard deviation of the "nodal degree"[32] (nd) within the region, σ_{max} is the standard deviation of the nodal degree of a fictitious 2-nodes network where nd_1 = 0 and nd_2 is the highest nodal degree in the actual network. Δ is the density of the network, computed as the ratio between the actual number of links and the maximum number of possible links. Links are identified by means of the flows. P_{SF} ranges from 0 to 1, where 0 indicates perfect monocentricity (i.e., centres are not linked to each other) and 1 perfect polycentricity. Potentially, all type of flows between centres can be used in the index, actually, data availability makes figures about commuters the most commonly used.

4.2.2 **Spatial structure and environmental quality**

Social costs arising from urbanization patterns have been raised the attention of scholars and policy-makers. However, cities have also been thought as good for the environment, for instance, by promoting "green behaviour" (Owen, 2010), urbanization has also negative impacts on the environment (Newman, 2006), for instance on global warming (Stern, 2008) or on local emissions. Urban forms and spatial structures are thought to affect the environmental sustainability of regions, as shown by policies contrasting sprawl (e.g. OECD, 2012) and favouring polycentric development (Commission of the European Union, 2011). The mechanisms through which spatial structure is thought to interfere with environmental quality involve mainly the transport and the residential sector[33]. Although some authors analysed both sectors together[34], most studies focus separately on each of the two aspects.

4.2.2.1 Transport

A key determinant of transport demand is the imbalance of housing vs. jobs (Bento et al., 2005), that is, the distance between dwellings and workplaces. This distance was shown to increase with urban dispersion (e.g. Orfield, 1997), involving, according to a wide corpus of literature, a positive relationship between sprawl and environmental pressures from transport. As shown by Camagni et al. (2002) an increase in dispersion and in the residential specialisation of the suburbs causes a shift towards private transport that jeopardize the supply of mass/public transport, which in turn, increases the use private transport. As a result,

[32] The nodal degree is the number of links that each centre has with the others.

[33] See EEA (2006) for a complete perspective.

[34] For instance, Perkins et al. (2009) calculated both embodied and operational energy consumption (and emissions) in private vehicles and buildings, finding that centralization and density do not necessarily yield lower (per capita) emissions.

we have a predominance of car journeys and high fuel consumption. The seminal study by Newman and Kenworthy (1989) has shown a strong statistical relationship between urban density and per capita oil consumption, due to increase in car use: the higher the density, the lower the travelled distances, the lower the oil consumption. Even if this study considered just the bivariate relationship — and hence it raised a debate on the effective drivers for energy demand and emissions[35] — it has the merit to clearly point out the role of spatial structure on environmental pressures. Later on, several articles investigated the issue, mostly questioning the effects *density* (and conversely dispersion) in transport demand, modal choice, transport energy consumption and emissions.[36]

For Italy, a recent paper by Travisi et al. (2010) analysed the impact of commuting in seven Italian provinces, focusing on density, jobs/housing balance and availability of rural areas. They found that the most sprawled municipalities within the regions showed higher impacts from travelling, driven by less self-containment of jobs (higher spatial mismatch) and subsequent loss of competitiveness of public transport.

It has to be noticed that not everybody agrees with the general consensus about the social costs coming from urban sprawl and about the merits of compact cities. Emphasising that the linkages between sprawl and environmental pressures are far from being clear. Some authors highlight the role of factors different than spatial structure,[37] others the positive effects of dispersion. Among the first authors, Ewing and Cervero (2010) found a weak role for sprawl when controlling for many factors affecting private transport demand, while Banister (2007, p. 129) found that the length of the trips is actually affected by the spatial structure built environment but their frequency and the modal choices are better predicted by socioeconomic factors. At the contrary, Glaeser and Kahn (2004) found that average commute times rise with population density, arguing that, in some circumstances, dispersed urban development may result in a decline in commuting demand, provided accessibility is improved. This may be the case for the 'edge cities' (Garreau, 1991), which are sub-urban areas in which functions are decentralized from centres and are characterised by high level of accessibility (usually they are found in shopping malls or highway interchanges).[38] Rodriguez et al. (2006), in analysing American metropolitan areas, found that higher population density is associated in longer travelled distances. Finally, the efficiency progress in the vehicles is sometimes

[35] See, e.g., Gordon and Richardson (1989).

[36] In 2010, a meta-analysis by Ewing and Cervero censed over 200 studies on built environment and travel (Ewing and Cervero, 2010).

[37] The main socio-economic factors affecting private transport demand are household income, preferences and lifestyle, and regulation.

[38] The link between development density and car pollution is similarly unclear. As discussed above, density itself is not necessarily related to spatial accessibility—implying that vehicle miles travelled per individual within a metropolitan area depend as much on micro-features of the area as on overall density. For instance, the appearance of edge cities, while leading to a less dense metropolitan area, may also result in a decline in commuting (and thus vehicle miles travelled per individual) as jobs are more decentralized within the urban area" (Glaeser and Kahn, 2003).

thought to compensate for the increasing distances characterising urban sprawl (Hawke et al., 1999).

Concerning polycentricity, as pointed out by several authors (Davoudi, 2003; Vandermotten, 2007), there is a general lack of empirical assessment about the effective role of it, particularly in terms of environmental sustainability. Some authors stressed the role of mass transit connecting centres (Cervero, 1995, Newman and Kenworthy, 1999) and Camagni et al. (2002) recognised that a 'wisely compact' and polycentric pattern of urban development - with high accessibility to mass transit - is desirable. Veneri (2011) found that polycentric metropolitan areas are more virtuous in terms of external costs of mobility, and that density is associated with lower environmental costs.

As general conclusion, it has to be admitted that the evidence on spatial structure and transport is far from being definitive. Firstly, and inevitably, research is made of case studies, which are difficult to generalize (Rodriguez et al., 2006). Secondly, most studies considered only bivariate relationships, such as those between density and travel, while it is far more difficult to include "the wide range of likely urban form and socioeconomic influences on travel" (Banister, 2007, 121), and to explore the dynamic processes involved.

4.2.2.2 Housing

Spatial structure is known to affect emissions from dwellings, as is the case, for instance, of the so-called "urban heat island": the phenomenon according to which urbanised areas are significantly warmer than their surroundings (Oke, 1973). However, when compared with the role of transport, the links between residential emissions and spatial structure are seldomly studied in the economic literature and more research is needed (Rickwood et al., 2008). This is an outcome of the complexity and heterogeneity that characterizes the issue, involving different geographic and climatic factors (Mitchell et al. 2010). Kahn (2002), who analysed the relationships between urban form and residential energy use, found no significant differences between suburban areas and centres. Wright (2008) found that domestic energy use is weakly correlated with urban form. However, form may be relevant at aggregate level (Mitchell et al., 2010).

According to Ewing and Rong (2008) spatial structure can influence energy consumption, and thus emissions, by means of three channels. A first channel is the urban heat island effect, which is more common in larger and denser cities. By raising local temperature, it makes energy demand higher for summer cooling but lower for winter heating. A second channel is the size and the type of housing stocks. In denser cities houses tend to be smaller and located in multi-residence buildings, two factors which involve lower energy requirements, while urban dispersion favours both the size of the houses (due to affordable land prices) and the presence of many detached or semi-detached houses (Holden and Norland, 2005; Rickwood et al. 2008). At the same time, dispersed areas may be characterised by younger housing stock, and hence higher energy efficiency, as compared to dense central areas where housing stock is older. As a consequence, the final impact can be ambiguous. Finally, a third channel is the electric transmission and distribution losses, which may be higher in dispersed areas. As pointed out by Ewing and Rong (2008) all the three effects - housing size and types, urban heat island, transmission and distribution losses - are ambiguous and call for empirical analysis.

To conclude, Figure 4.23 provides a synthetic overview of the links, illustrated in this section, between spatial structure and emissions.

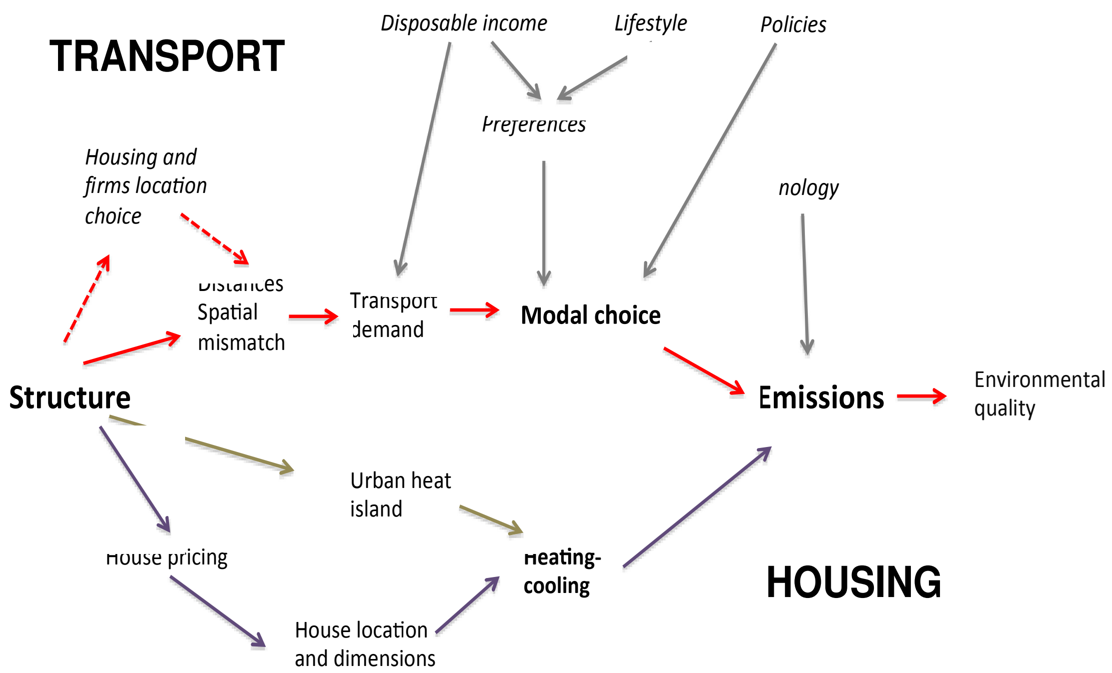


Figure 4.2: Links between spatial structure and emissions

4.3 Italian empirical evidence

The present and next sections report about our empirical analysis. First some figures about the relevance of transport and housing emissions are shown, and then the econometric analysis is presented. The following figures, based on the data available in the Italian national emissions inventory,[39] summarise the recent emission trends of CO_2 and PM_{10} in Italy, both total and

[39]http://www.sinanet.isprambiente.it/it/sia-ispra/serie-storiche-emissioni/serie-storiche-delle-emissioni-nazionali-snap-1980-2010/view

disaggregated according to the originating sector (SNAP classification). Figure 4.3 shows CO_2 emissions, which are available for the period 1980-2012. As well known, they increased from 1985 to the mid of the 2000s and decreased back to the 1980s levels due to the economic crisis. Emissions from road transport, the bottom series, showed a different behaviour, increasing steadily until 2007; moreover their level in 2012 is almost double than in 1980. Figure 4.4 reports PM_{10} emissions in Italy over the period 1990-2012. Their trend has been strongly affected by the abatement policies and by the substitution of oil with natural gas in the electrical power plants.

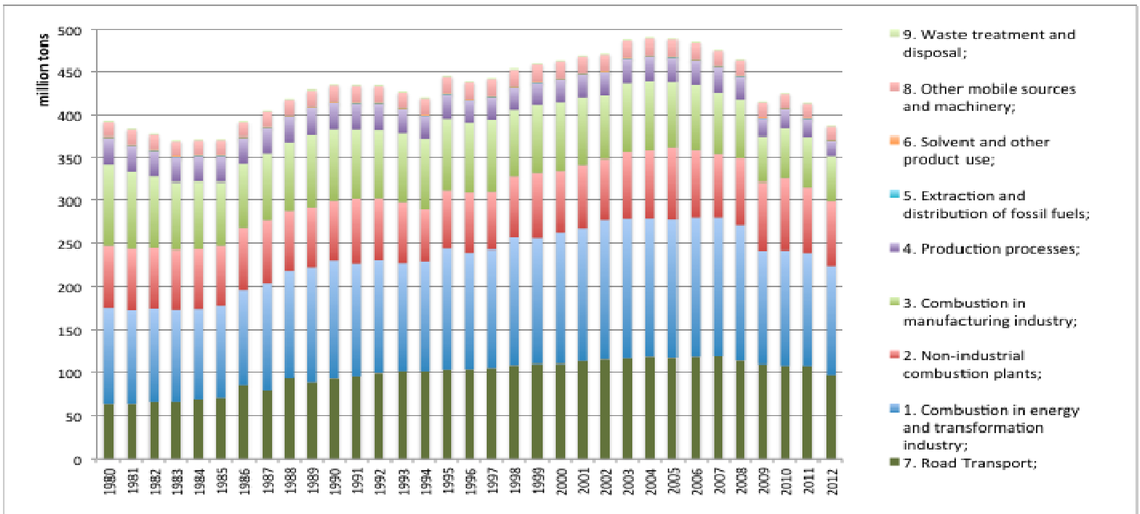


Figure 4.3: CO_2 in Italy from 1980 to 2012.
Source: ISPRA (Sinanet)

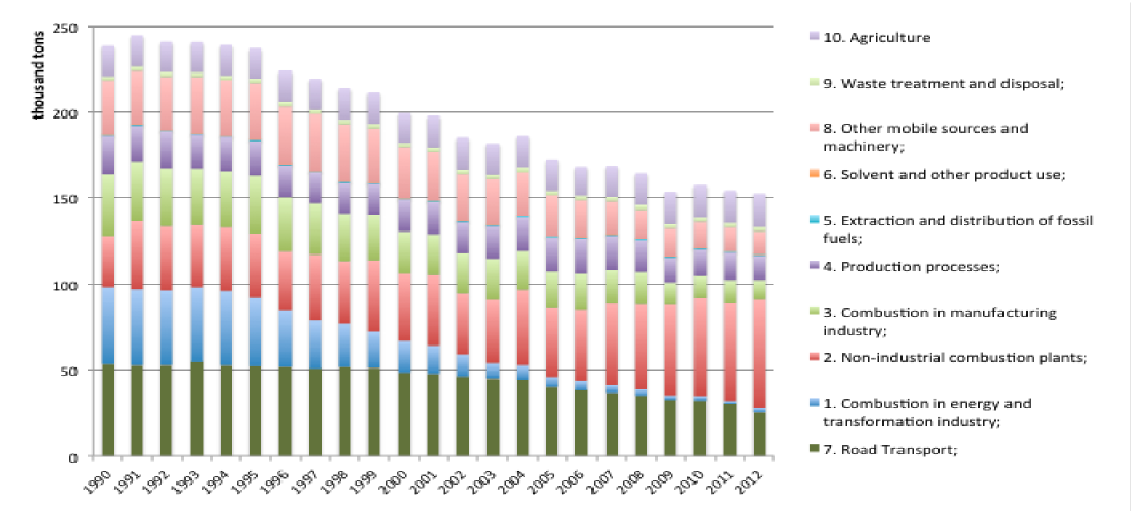


Figure 4.4: PM_{10} in Italy from 1990 to 2012.
Source: ISPRA (Sinanet)

Table 4.1 summarises the contribution of road transport to total emissions across time. Road transport has a key role in PM_2 and CO_2 emissions accounting for about ⅕ - ¼ of the total. Its contribution decreased for PM10 while increased for CO2, rising from 16% in 1980 (not shown in the table) to 25% in 2010. The table also reports the share of CO2 emissions attributable to private transport.

Table 4.1: The contribution of road transport to total emissions (%)

	1990	1995	2000	2005	2010
PM_{10}	22.4%	22.1%	24.3%	23.3%	20.4%
CO_2	21.5%	23.3%	23.9%	24.0%	25.5%
of which for private transport	9.5%	11.0%	15.3%	18.2%	19.4%

Data source: ISPRA (Sinanet)

The trends in transports are also confirmed by data on mileages, which are considerably higher in 2010 than in 1990 (see Table 4.2).

Table 4.2: Evolution of mileage by type of vehicle *(10^9 vehicles-km/y)*

	1990	*1995*	*2000*	*2005*	*2010*
Passenger cars and buses	308	365	397	422	406
Moto	31	39	45	40	39
Goods transport	68	75	89	99	104

Adapted from ISPRA 2014, p. 91

It is also important to assess separately the passenger private transport. To this purpose, Figure 4.5, by zooming on the lowest bars of Figure 4.3, shows that passenger private transport has increased more than the other road transports, with its $C0_2$ emissions going from less than 60% of total road transport in the 1980s to more than 65% afterwards.

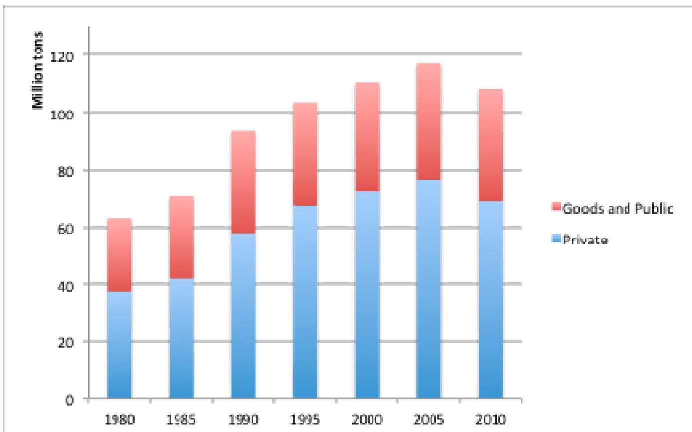


Figure 4.5: CO_2 emissions from transport, private vs. goods and public transport
Source: Own elaboration on ISPRA-SINANET data

Commuting represents one of the most important sources for mobility demand and hence emissions. Its role has been increasing over the last decades. Actually, commuting distances are, despite the crisis, considerably higher than at the beginning of the 2000s. This is confirmed by the estimates by ISFORT (2011) according to which the total mileage in a working day (see Figure 4.6) is considerably higher in the second half of the 2000s, despite the average number of travels remained stable (Figure 4.7).

Figure 4.7 gives also some important hints about modal choices, showing a sharp decline in “walking and cycling”. One also can observe that the economic crisis has probably curbed private cars use in favour of public transport.

Figure 4.6: Evolution of passengers*km in a working day
(Source: ISFORT, 2011)

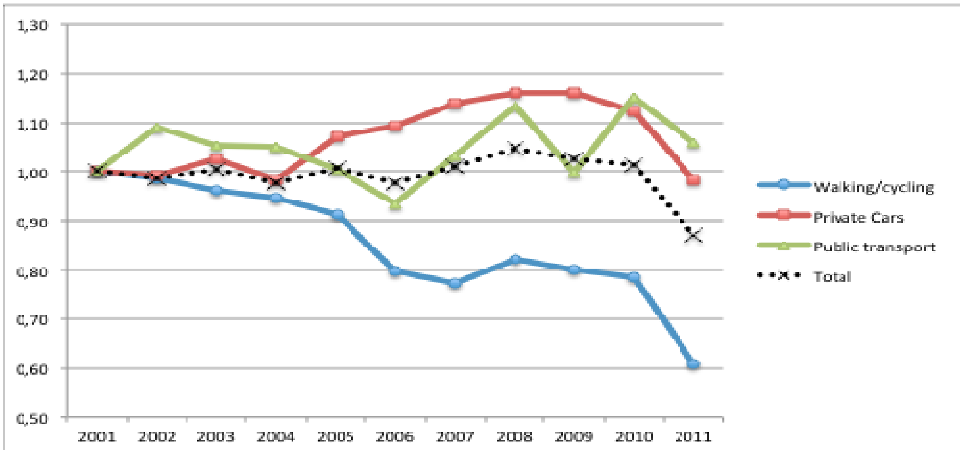


Figure 4.7: The evolution of modal choices in Italy: the index numbers of the average number of travels in a working day, 2001-2011
(Source: ISFORT, 2011)

Also for residential emissions, trends differ between CO_2 and PM_{10} (see Figure 4.8). CO_2 emissions in residential sector are rather stable, with a tendency to decrease. PM_{10}s in the residential sector show an increasing trend, while total emissions, as highlighted before, fell considerably.

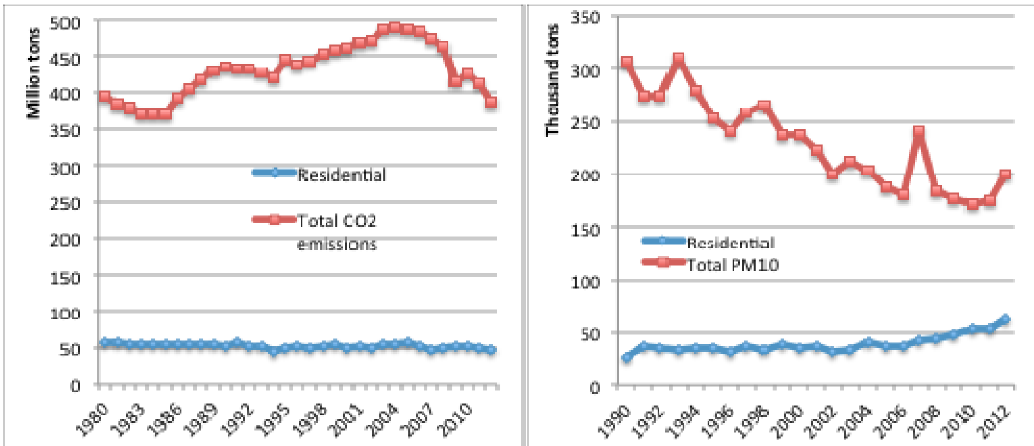


Figure 4.8: CO_2 and PM_{10} emissions trends - total and residential sector

4.4 An empirical analysis

As discussed before, one can expect that spatial structure affect CO_2 and PM_{10} emissions both from transportation and house heating. To test this hypothesis we performed several (OLS) regression estimates for Italy at NUTS 3 level and for the years 1990, 2000 and 2005. We report here the results of our empirical analysis.

4.4.1 Data sources

Data for emissions are available online at SINANET, which is the official Italian network contributing to the *Environmental Information and Observation Network* of the European Environmental Agency (EEA). Data are currently updated every five years.

Spatial structure, as discussed in section two, has different dimensions and measures, hence a wide range of different indicators from different sources has been used. Functional polycentricity indexes have been computed by using commuting flow data from the Population Census of Italian Statistical Bureau (ISTAT). Morphological polycentricity indexes have been computed by using data on population from the demographic database of ISTAT.[40] Dispersion indexes have been calculated by using both population and land use data. The latter have been

[40] http://demo.istat.it/

retrieved from CORINE Land Cover maps provided by EEA.[41]

Following the theoretical discussion of section 4.2, we used the opposite of net density as a proxy for sprawl, the opposite of absolute value of the coefficients of the rank size estimates as a proxy for morphological polycentricity, and the PSF index as a proxy for functional polycentrity[42]. We also included several control variables, as shown in Table 4.3.

Table 4.3: Control variables and statistical sources

Variable	*Statistical source*
Income (value added)	ISTAT territorial accounts
Number, average age, and fuel type of private cars	Italian Automobile Club[43]
Public transport accessibility	ESPON Database[44]
House age and number of rooms	ISTAT Census
Surface and altitude	ISTAT Census
Cool days	Italian decrees[45]

The time structure of data availability forced us to focus only on years 1990, 2000 and 2005. Emissions are available for 1990, 1995, 2000, 2005, 2010; Census Commuting Flows for 1991 and 2001[46], land cover data for 1990, 2000 and 2006[47].

Due to strong changes in the administrative units and boundaries after 1990 and also to differences in some control variables between 1990 and the following years, we checked the relevance of the spatial structure separately for 1990, while we pooled data for 2000 and 2005. Hence n=95 for 1990 and n=206 for 2000 and 2005.

4.4.2 **Main results**

We report here the most relevant results, while the appendix contains detailed regression tables. To interpret the results one has to consider that we estimated emissions in absolute terms since per capita emissions are not relevant for the quality of the environment, which

[41]http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-1990-raster-2

[41]http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-raster-2

[41]http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2

[42] Obviously, net density and rank size coefficient are inverse indicators, while PSF is direct. As customary ***, **, and * indicate respectively 1%, 5%, and 10% significance level.

[43] http://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/autoritratto.html

[44] http://www.espon.eu/main/Menu_ToolsandMaps/ESPON2013Database/

[45] http://clisun.casaccia.enea.it/Pagine/GradiGiorni.htm

[46] Since the index computed from census commuting flows are relatively stable in time, as shown by the comparison of 1991 and 2001, we proxied 2005 data with 2001 ones.

[47] Data for 1991, 2001 and 2006 have been considered valid respectively for 1990, 2000 and 2005.

actually depends on total pressures. Only for the purpose of checking our results, we also used per capita values as regressands, which involved sometimes changes in the significant regressors. However, this strongly questioned the interpretation of the absolute terms results only in two cases in which the sign of the estimated coefficient changed (functional polycentricity for CO2 and morphological polycentricity for PM10, both in 1990).

Emissions from residential heating are easily summarised since the only clear evidence about a role for spatial structure is that, for all periods considered, sprawl affects positively PM_{10} emissions (see Tables in the appendix).[48]

More evidence is found for emissions from transport sector. Table 4.4 summarises the effects of the three spatial structure indicators on CO_2 and PM_{10} from the private transport sector by reporting the sign and the significance level of our estimates (see Tables 5-8 in the appendix for detailed figures). As immediately evident from the table, the results for 1990 are more mixed than for the 2000-2005 pool. The only clear evidence for 1990 is that sprawl is not significant. For 2000-2005 data suggest that both sprawl and polycentricity increase CO_2 emissions. PM_{10} are positively affected by polycentricity, with a very low evidence of a positive role of sprawl.

Table 4.4: The role of spatial structure for transport emissions, summary of results

	2000 & 2005				1990			
	CO_2		PM_{10}		CO_2		PM_{10}	
	abs	p.c.	abs	p.c.	abs	p.c.	abs	p.c.
Sprawl	+ **	+ ***	n.s.	+ **	n.s.	n.s.	n.s.	n.s.
Morphological Polycentricity	+ *	+ ***	n.s.	+ ***	n.s.	+ ***	- ***	+ ***
Functional Polycentricity	+ ***	+ ***	+ ***	+ ***	- ***	+ ***	n.s.	+ ***

4.5 Conclusions

The aim of this chapter was to contribute to the debate about the links between spatial

[48] CO_2 emissions might be affected (10% sign. level) either by morphological polycentricity (absolute terms) or by sprawl (per capita terms). See appendix, Table 4.9 and

Table 4.10).

structure and emissions from private transport and residential heating. The literature that was surveyed in section 4.2 highlights several mechanisms through which spatial structure can play an important role in affecting emissions. Given the framework offered by the survey we moved to empirically analyse the Italian case. After having presented the main figures and trends at the country level, we moved to the provincial level and performed a regression analysis using data for the years 1990, 2000 and 2005.

As expected, sprawl coefficients are significantly positive for PM_{10} emissions from residential heating in all years, and for CO_2 emissions from transport in the 2000s. This evidence supports the idea that compact and dense urban regions reduce emissions from private motorized transport.

Also polycentricity was found to have a role, which is however opposite to what is usually thought. In the 2000s the proxies for polycentricity show significant and positive coefficient both for CO_2 and for PM_{10}. This does not need to be interpreted that polycentricity increases environmental pressures. However it is a strong evidence that polycentricity alone does not reduce emissions. Actually, polycentricity might facilitate planning and long-term development policies oriented towards the reduction of private vehicle flows, and hence emissions, between centres (Bertolini, 2012). To verify this hypothesis one would need additional control variables, such as proxies for the quality of public transport or for the degree of multifunctional land use, which unfortunately were not available for our case study.

4.6 APPENDIX: Regression results

4.6.1 Transport emissions

Table 4.5: CO_2 cars: absolute emissions

	2000-2005				1990	
	Signif.	*Coeff.*	*Std. Err.*	*t*	*Signif.*	*sign*
-NET_density	**	485,9	232,9	2,09	n.s.	
-BETA_all	*	23625,8	12346,7	1,91	n.s.	
PSF	***	287190,1	50380,5	5,7	***	-
Population	***	1,373	0,02	57,83	***	+
Population^2	***	-3,110E-08	8,34E-09	-3,73	n.s.	
Added Value (p.c.)	*	1,973	1,06	1,86	**	-
Share of cars aged < 5 yrs.	***	-237989,6	72026,4	-3,3	**	-
dummy 2005	***	-23332,4	8474,8	-2,75	/	
Constant		42473,8	22566,4	1,88		
	R^2=0,99				R^2=0,99	

Table 4.6: CO_2 cars: per capita emissions

	2000-2005				1990	
	Signif.	*Coeff.*	*Std. Err.*	*t*	*Signif.*	*sign*
-NET_density	***	-7,43E-04	0,0002557	-2,91	n.s.	
-BETA_all	***	-0,1203	0,0206468	-5,83	***	-
PSF	***	0,4728	0,0465168	10,16	***	+
Population	***	-1,59E-07	1,66E-08	-9,63	***	-
Population^2	***	2,94E-14	4,79E-15	6,15	***	+
Added Value (p.c.)	*	-2,70E-06	6,71E-07	-4,03	***	-
Province Altitude (av.)	***	0,0290408	0,0062868	4,62	***	-
Dummy_central_Italy	n.s.				***	-
Constant		1,66	0,0383339	43,19		
	R^2=0,74				R^2=0,68	

Table 4.7: PM_{10} cars: absolute emissions

	2000-2005				1990	
	Signif.	*Coeff.*	*Std. Err.*	*t*	*Signif.*	*Sign*
PSF	***	178,5015	29,05093	6,14	***	+
Population	***	0,0005715	0,0000253	22,62	***	+
Population^2	***	-2,14E-11	7,01E-12	-3,05	n.s	
Share diesel cars	***	26,38383	5,648485	4,67	n.a.	
Dummy_2005	***	-63,44929	7,354407	-8,63	/	
Share of cars aged < 5 yrs.	n.s.				***	-
Dummy_central_Italy	n.s.				**	-
Constant		-12,24778	10,74699	-1,14		
	R^2=0,97				R^2=0,99	

Table 4.8: PM_{10}cars: per capita emissions

	2000-2005				1990	
	Signif.	*Coeff.*	*Std. Err.*	*t*	*Signif.*	*Sign*
-NET_density	**	2,34E-07	1,20E-07	1,94	n.s.	
-BETA_all	***	0,0000513	8,68E-06	5,91	***	-
PSF	***	0,0002413	0,0000226	10,68	***	+
Population	***	-8,29E-11	7,82E-12	-10,6	***	-
Population^2	***	1,52E-17	2,45E-18	6,21	***	+
Added Value (p.c.)	***	-1,44E-09	3,39E-10	-4,23	***	-
dummy_2005	***	-0,0001732	3,38E-06	-51,22	/	
Constant		0,0007755	0,0000157	49,33		
	R^2=0,94				R^2=0,68	

4.6.2 House heating emissions

Table 4.9: CO_2 house heating: absolute emissions

	2000-2005			
	Signif.	*Coeff.*	*Std. Err.t*	
-BETA_all	*	109997,3	60535,93	1,82
Population	***	0,9410219	0,1408003	6,68
Added Value (p.c.)	***	42,80789	8,305688	5,15
Province Altitude (av.)	***	-114047,8	38926,1	-2,93
Cool days	***	179,2144	47,80887	3,75
Constant		0,0007755	0,0000157	49,33
	R^2=0,94			

For 1990 none of the coefficients of the indicators of spatial structure was significant

Table 4.10: CO_2 house heating: per capita emissions

	2000-2005			
	Signif.	*Coeff.*	*Std. Err.t*	
-NET_density	*	-0,3832088	0,2285724	-1,68
Added Value (p.c.)	***	0,0000402	5,65E-06	7,12
Province Altitude (av.)	***	0,2648122	0,0554506	4,78
Cool days	***	0,0005424	0,0000729	7,44
Constant		-1,531823	0,1285907	-11,91
	R^2=0,72			

For 1990 none of the coefficients of the indicators of spatial structure was significant

Table 4.11: PM_{10} house heating: absolute emissions

	2000-2005				1990	
	signif.	*Coeff.*	*Std. Err.*	*t*	*signif.*	*Sign*
Population	***	0,0005264	0,0000396	13,28	***	+
Province Altitude (av.)	**	43,4136	18,0749	2,4	**	+
-NET_density	***	291,8156	105,2175	2,77	**	+
Constant		102,0146	47,82676	2,13		
	R^2=0,81				R^2=0,75	

Table 4.12: PM_{10} house heating: per capita emissions

	2000-2005				1990	
	signif.	*Coeff.*	*Std. Err.*	*t*	*signif.*	*sign*
Province Altitude (av.)	***	0,0001362	0,0000338	4,03	***	+
-NET_density	**	0,0005234	0,000216	2,42	**	+
Constant		0,000886	0,0000817	10,84		
	R^2=0,11				R^2=0,18	

5 Conclusions

5.1 Main results

This thesis aimed to investigate the role of spatial structure for economic development, with a special focus on the empirical evidence that can be drawn from Italy. The work was grounded on urban and regional economics.

The introduction, Chapter 1, gave the rationale of the work. Economic analysis has been giving increasing interest on the spatial aspects, since agglomeration economies, which are related to geography and distance, have been recognised to be crucial drivers for the growth of cities, regions and countries. The main research question of the thesis was to investigate whether agglomeration advantages are linked to the spatial organization of economic activities across regions. In fact, urban regions have been characterized by spatial changes in the last decades, which may have affected agglomeration effects. The work focused on two major aspects of spatial structure, polycentricity and urban dispersion, which show increasing interest both in the academic literature and territorial policies, and require more empirical analysis. The thesis gave particular attention to polycentricity, since it has become a key tool addressing spatial policies of European States, as described by sections 1.3 and 1.5. At the same time, urban dispersion has started to generate increasing concerns about its effects on the economy and the environment (Section 1.4).

Despite the dynamics in regional urban structure and the increasing interest on polycentricity and urban dispersion, little attention has been devoted to the links between those two aspects of spatial structure and economic development – especially regarding the empirical assessment. In many cases it appears that those notions, especially polycentricity, may be just ‘code words’, or ‘hegemonic concepts’, i.e. “simple concepts designed to persuade decision-makers” (Baudelle, 2007, p.76).

The thesis argued that a possible reason for the research gaps in the applied analysis on spatial structure and development may be the complexity and fuzziness associated with polycentricity and dispersion, which determined a variety of definitions and measures for the two concepts. This was especially the case for polycentricity and polycentric development, since they are relatively new concepts in spatial economics. Given the variety of definitions and measures that may be adopted, it is difficult to compare existing studies.

For this reason, Chapter 2 aimed to analyse the issues of definition and measurement of spatial structure by combining the several aspects involved. Such a research strategy is not very 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. By reviewing the theoretical and empirical literature, the chapter showed the dimensions involved in polycentricity, namely the morphological and the functional dimensions, and the measures that can be associated to them. It also listed the aspects of urban dispersion and its possible measures. The Appendix to the chapter (Section 2.5) applied many of the measures to the analysis of Italian NUTS-2 regions and the links between polycentricity and the three main dimensions of regional development, as addressed by EU policy: economic competitiveness, social cohesion and environmental sustainability. The appendix showed, firstly, that despite the differences between functional and morphological approaches, the two dimensions are quite correlated. Secondly, with reference to the effectiveness of polycentricity as a normative goal, the empirical analysis displayed that polycentricity in Italian regions is not always a virtuous model of spatial development, especially in terms of social cohesion. This is in contrast with the idea of ESDP, but consistent with other European studies on this topic (Meijers and Sandberg, 2008). Correlations between polycentricity and several environmental indicators were also not univocal, the same happens when competitiveness is taken into account. Hence, the analysis confirmed the idea that the polycentric spatial structure – taken alone – is far from being an effective tool to reach those important policy aims, at least when considering Italian NUTS 2 regions. However, a central point that must be clarified, especially from a theoretical perspective, is the spatial scale at which polycentricity can exert a virtuous role – in other words, the level at which *regional* externalities can exploit – and thus the appropriate scale for potential policy actions.

The evidences highlighted in Chapter 1 and the preliminary results provided by Chapter 2 stimulated the empirical analysis carried which has been showed in the second part of the thesis. Here the aim was to analyse the effects of spatial structure respectively on economic competitiveness and environmental sustainability. The analysis reported by Chapter 3 investigated how spatial structure affects labour productivity in Italian provinces. From the empirical analysis – carried out by means of regressions that also considered some relevant methodological problems, such as endogeneity and spatial dependence – some results were found to assess the role of spatial structure. Firstly, results confirmed that productivity increases with size: this is consistent with the idea that urbanization externalities positively affect productivity. Secondly, dispersed regions showed lower productivity than centralised ones. Hence, we can infer that proximity (enhanced by density) is relevant for agglomeration benefits, and that sprawl may have possible negative economic effects. Polycentricity did not have a positive effect on economic performances. Finally, the effect of the overall strength of agglomeration forces seemed to change on the basis of the size of the regions that were included in the analysis. On the one hand, size always had a positive impact on productivity, on the other hand the magnitude and the significance of the related coefficient was higher for small regions and then decreased for larger regions. The productivity of small-sized regions has previously been thought to be positively affected by polycentric structures, in order to compensate for a smaller size, but this effect was not empirically verified by the analysis reported here.

The Appendix to Chapter 3 tackled the issue of the identification of the appropriate units of analysis to investigate the characteristics of spatial structure and their implications. Hence, the appendix considered a definition of Functional Urban Region (FUR) whose boundaries are not constrained by administrative settings and reflect the actual spatial dimension of regional economic processes. Then, the appendix reports the results of an analysis that considered – by means of regression analysis – employment and population growth of Italian FURs as measures of territorial economic development. Results showed that monocentric regions grow more than polycentric regions and that this result is stronger for smaller regions. This evidence does not support the hypothesis that polycentric regions with dense relationship can substitute the benefits of a single strong agglomeration. On the other hand, dispersion was also associated with higher growth. This result can be explained by congestion costs that may be relevant in centralised regions, as well as a low relevance of physical proximity between economic agents within functional regions.

Chapter 4 reported and discussed the results of the empirical analyses on the effects of urban spatial structure on emissions. The survey of the most relevant literature provided the framework to empirically analyse the causal links between spatial structure and emissions. Transport and housing emissions represent two of the major sectors that link spatial structure and environmental pressure. The chapter also illustrated some figures about the relevance of the theme of transport and housing emission in Italy. The impact of spatial structure on emission originated by the two sectors were assessed through regression analysis on Italian provinces, which considered CO_2 and PMs emissions. Results showed that emissions from transport sector are likely to be affected more than emissions from house heating. Main findings were that spatial structure affects CO_2 emissions from private transport and PMs from housing emissions. No evidence was found for polycentricity to reduce emissions.

5.2 Discussion and further steps

The results of the empirical part of the thesis confirm that spatial structure can have a role for economic competitiveness and environmental pressure in Italian provinces. However, the findings question some of the policy statements about the role of spatial structure as a tool in fostering a smart, inclusive and sustainable development. This is in particular the case of polycentric development. Notwithstanding the role of polycentric development in strategic EU policy documents, such as the ESDP and the Territorial Agenda EU 2020, in the case of Italian NUTS-3 regions polycentricity does not enhance labour productivity neither gas emission levels. At the contrary, polycentric development is associated with low productivity and – in some cases- higher emissions.

With reference to labour productivity, the former finding suggests that, at least in the sample of Italian NUTS-3 regions productivity, relational proximity between different centres cannot be a substitute for physical proximity in monocentric regions. Hence, despite the fact that cities and metropolitan areas are now a regional phenomenon, monocentric regions are still stronger in terms of agglomeration externalities: in other words, the hypothesis of regionalisation of agglomeration benefits and 'borrowed size' seems to be rejected. Still the presence of large centres matters for regional competitiveness, while networks in regions appear not to be fully substitute for agglomeration.

The analysis carried out may suffer from some drawbacks, which may affect the direction of the effects of polycentricity. As highlighted in Chapter 1, the choice of units of analysis can affect the results. NUTS-3 regions, being administrative units rather than functional units, may be affected by MAUP. However, Section 1.6 discussed the rationale for using NUTS-3 regions for aggregate productivity analysis, which is in line with research carried out at European level (including many ESPON reports). Additionally, the negative outcomes from polycentricity have also been found by taking into account productivity growth in NUTS-2 regions, which also show how size and the presence of a large centre matter for competitiveness (Appendix 2.5), as well as functional regions (Appendix 3.6).

Another critical issue regards the measurements of networks that measure polycentricity degree within regions. Data availability bounded the analysis to measure relationships between centres in regions in terms of commuting flows. However, it is well known that commuting does not exhaust the system of relationships between regions. Further analysis should consider other possible flows, such as information, goods, etc. Another point, also linked with poor data availability, is that commuting flows were available to us just for a couple of years, and the last available flows date to 2001. This fact questions the current validity results of the thesis, given also that economy of Italian regions is changing since the beginning of the crisis (2008). Further research should address this issue.

Sectoral composition may be another issue to be taken into account. Sectoral mix within regions may play an important role in understanding which spatial structures are more efficient. In fact, although sectoral composition was considered in this analysis, a more thorough study by sector might be useful, since some sectors may only benefit from physical proximity while others may take advantage of relational and functional relations at a regional level. These issues represent promising questions for further research on this topic.

With reference to the environmental effects of polycentricity, the analysis focused on transport and house heating emissions, which have been thought to be the most relevant sectors in which polycentricity may have a role. Polycentricity appears not to be linked with lower emissions. This result does not necessarily mean that polycentricity alone increases emissions. Actually, as discussed in the chapter, polycentricity can be a tool within a wider planning and long term development strategies, which should be oriented towards the reduction of private vehicle flows between centres. To verify this hypothesis one would need additional control variables, such as proxies for the quality of public transport or for the degree of multifunctional land use, which unfortunately were not available for our case study.

With reference to housing sector, there are no links between polycentricity and reduction of emissions from hose-heating. In this case the NUTS-3 spatial level could be too large for the analysis of house heating emissions, which should focus more on the spatial structure within city areas. In both dimensions of economic competitiveness and environmental pressure, urban dispersion has been found to be linked with poorer performance. In the case of labour productivity, dispersed regions show lower productivity than centralised ones, while in the case of gas emissions, urban dispersion is always associated with higher emissions from private transport. Those results, which are in line with existing literature, would need to be tested by using several definitions and measures of sprawl. Galster (2001) provided a framework of many dimensions. For reason of time and space, this analysis focused on some of them, by selecting the indicators based on those used by relevant literature. However, recent works made advancements in terms of measurement of sprawl (Burchfield et al. 2006; Arribas-Bel et al., 2011) which should be taken into account in future research.

For time and data constraints, the research presented in this thesis did not expletively take into account the third dimension of regional development that have been addressed by EU strategic papers: territorial cohesion. As seen in Chapter 2, with the European Spatial Development Perspective polycentricity turned from an analytical tool to a normative agenda. To achieve a more balanced urban system. Territorial cohesion became, hence the most prominent task of territorial policies, in order to exploit territorial diversities of the EU. TA 2020 confirmed and reinforced the quest for territorial cohesion. In the vision of both ESDP and TA 2020, spatial structure, and in particular polycentricity, is a tool to boost both growth and cohesion. In other words, by means of polycentric development the trade-offs between efficiency and equity should be overcome (Table 5.1).

Table 5.1: Objectives and spatial strategies for competitiveness and cohesion

	Competitiveness	Territorial cohesion	Competitiveness and cohesion
Spatial Strategy	Reinforce major poles	Reduce spatial disparities	Conciliate Gothenburg and Lisbon
Instrument	Growth poles	Zoning	Polycentricism
Outcome	Efficiency, disparities	Solidarity	Territorial equity

Source: Baudelle, 2007, p. 78

However, the literature is quite sceptical about the effects of polycentric development in lowering regional disparities (Davoudi, 2007; Meijers and Sandberg, 2008). Also the results of an analysis on Italian NUTS-2 level, as shown in Appendix 2.5, showed that the higher the polycentricity, the more unequal the income distribution. The results provided by the empirical analysis shown in Chapter 3, highlighting that polycentricity is not positively linked with competitiveness may question also about the effectiveness of spatial structure on the inclusive dimension of development, and call for detailed research, which will be the natural step forward from this thesis, once appropriate data on territorial cohesion (such as income distribution) will be available.

To sum up, from the analytical discussions offered by Part 1 and the empirical analysis presented in Part 2 of the thesis, it is possible to infer that an optimal spatial structure – in terms of the trade-off between economies and diseconomies of agglomeration – may not be easily identifiable. This holds especially for the monocentricity/polycentricity dichotomy, while since several efficient structures can exist on the basis of the size and on other relevant characteristics of the regions, such as the sectoral specialization, the rank within the national and international hierarchy, the network relationships between regions.

Spatial structures change as they adapt so as to find the right trade-off between economies and diseconomies of agglomeration. The final result depends on economic and functional characteristics of cities and regions. The spatial structures are therefore the result both of a process that self-organizes to achieve more efficient outcome – in terms of polycentricity and centralization – and of slow and path dependent processes, including processes of coalescence of old and previously independent centres.

Identifying what actually are the benefits of polycentric areas – and conversely the drawbacks of urban sprawl – can help policy makers to question the normative aspects related to the concept of spatial structure and to eventually help understanding the possible implication of different patterns of development of the territory in achieving regional development by reconcile the goals of economic competitiveness, social cohesion and environmental sustainability. However, a long-run perspective both in the analysis and policy is needed, since urban system are characterised by strong inertia and path-dependence that allow only for marginal changes in the short run (Batty, 2001). Hence, as final message, this thesis calls for an analysis of the evolution of regional spatial structures in the long run, both considering past history and the possible scenarios for the future.

Bibliography

Albrechts, L. (2001). How to proceed from image and discourse to action: as applied to the Flemish Diamond. *Urban Studies*, *38*(4), pp. 733-745.

Alonso, W. (1964). *Location and land use*. Cambridge, MA: Harvard University Press.

Alonso, W. (1973). Urban zero population growth. *Daedalus*. *109*, pp. 191-206.

Anas, A., Arnott, R., & Small, K. A. (1998). Urban spatial structure. *Journal of Economic Literature*. *36*, pp. 1426-1464.

Anderson, N., & Bogart, W. (2001). Identifying and characterizing employment centers in polycentric metropolitan areas. *American Journal of Economics and Sociology*, *60*(1), pp.147–169.

Anderson, W. P., Kanaroglou, P. S., & Miller, E. J. (1996). Urban form, energy and the environment: a review of issues. Evidence and policy. *Urban studies*, *33*(1), pp.7-35.

Auerbach, F. (1913). Das gesetz der bevölkerungskonzentration. *Petermanns Geographische Mitteilungen*, *59*, pp.73-76.

Banister, E. (2007). Cities, urban form and sprawl. A European perspective. In OECD, *Transport, Urban Form and Economic Growth*, *Report of the One Hundred and Thirty Seventh Round Table on Transport Economics* (pp. 113-142). Paris: OECD Publishing.

Barca, F. (2009). *An agenda for a reformed cohesion policy. A place-based approach to meeting European Union challenges and expectations*. Independent Report prepared at the request of Danuta Hubner, Commissioner for Regional Policy. Brussels: European Commission.

Barca, F., McCann, P., & Rodríguez-Pose, A. (2012). The case for regional development intervention: place-based versus place-neutral approaches. *Journal of Regional Science*, *52*(1), pp. 134-152.

Bailey, N., & Turok, I. (2001). Central Scotland as a polycentric urban region: useful planning concept or chimera?. *Urban Studies*, *38*(4), pp. 697–715.

Bart, I. L. (2010). Urban sprawl and climate change: A statistical exploration of cause and effect, with policy options for the EU. *Land Use Policy*, *27*(2), pp.283–292.

Batty, M. (2001). Polynucleated urban landscapes. *Urban studies*, *38*(4), pp. 635-655.

Baudelle, G. (2007). Polycentrism, equity and social cohesion in Europe. In Cattan, N. (ed.), *Cities and networks in Europe. A critical approach to polycentrism* (pp. 75-79). Montrouge, France: John Libbey Eurotext.

Becattini, G. (1979). *Mercato e forze locali: Il distretto industriale*. Bologna: Il Mulino.

Becattini, G., Bellandi, M., Ottati, G., & Sforzi, F. (2003). *From industrial districts to local development: an itinerary of research*. Cheltenham: Edward Elgard Publishing.

Beckmann, M. J. (1958). City hierarchies and the distribution of city size. *Economic Development and Cultural Change*, *6*, pp. 243-248.

Beckmann, M. J., & McPherson, J. C. (1970). City size distribution in a central place hierarchy: an alternative approach. *Journal of Regional Science*, *10*(1), pp. 25-33.

Beguin, H. (1984). The shape of city-size distributions in a central place system. *Environment and Planning A*, *16*(5), pp. 749-758.

Bertolini, L. (2012). Integrating mobility and urban development agendas: a Manifesto. *disP-The Planning Review*, *48*(1), pp. 16-26.

Bertolini, L., & Dijst, M. (2003). Mobility environments and network cities. *Journal of urban design*. *8*(1), pp. 27-43.

Bento, A. M., Cropper, M. L., Mobarak, A. M., & Vinha, K. (2005). The effects of urban spatial structure on travel demand in the United States. *Review of Economics and Statistics*, *87*(3), pp. 466-478.

Blumenthal P., Wolman, H. L., & Hill E. (2009). Understanding the economic performance of metropolitan areas in the United States. *Urban Studies*, *46*(3), pp. 605-627.

Boix, R. (2002). *Instrumentos de análisis de redes en economía urbana: Caracterización de redes de ciudades mediante el análisis de cuatro estructuras urbanas simuladas*. Oviedo: V Encuentro de Economia Aplicada.

Boix, R., & Trullén, J. (2007). Knowledge, networks of cities and growth in regional urban systems. *Papers in Regional Science*, *84*(4), pp.551-574.

Boix, R., & Veneri, P. (2009). Metropolitan areas in Spain and Italy. *IERMB Working Paper in Economics*, nº 09.0, Institut d'Estudis Regionals i Metropolitans de Barcelona.

Boschma, R. (2005). Social capital and regional development: an emprirical analysis of the Third Italy. In R. Boschma and R. Kloosterman (Eds.). *Learning from clusters* (pp. 139–168). Amsterdam, the Netherlands: Springer

Bossard, M., Feranec, J., & Otahel, J. (2000). CORINE land cover technical guide – Addendum 2000, *Technical report No 40*, Copenhagen: European Environment Agency.

Brakman, S., Garretsen, H., Van Marrewijk, C., & Van Den Berg, M. (1999). The return of Zipf: towards a further understanding of the Rank-Size Distribution. *Journal of Regional Science*, *39*(1), pp. 183-213.

Brunet, R. (1989). *Les villes europeénnes: Rapport pour la DATAR*, Montpellier: Reclus.

Burchfield, M., Overman, H., Puga, D., & Turner, M. A. (2006). Causes of sprawl: A portrait from space. *The Quarterly Journal of Economics*, *121*(2), pp. 587–633.

Burger, M. J., & Meijers, E. (2012). Form follows function? Linking morphological and functional polycentricity. *Urban Studies*, 49(5), pp. 1127-1149.

Burger, M. J., van Oort, F.G., & van der Knaap, B. (2009). A treatise of the geographical scale of agglomeration externalities and the modifiable areal unit problem. *Scienze Regionali, 9*(1), pp. 19-29.

Calafati, A. G. (2005). On the use of local labour systems. *Scienze Regionali*, *4*(1), pp. 139–144.

Calafati, A. G. (2007). La città come 'sistema progressivo': evoluzione strutturale e sviluppo economico. *Scienze Regionali*, *6*(3), Supplement, pp. 83-111.

Calafati, A. G. (2009). Macro-regions, local systems and cities: the conceptualisation of territory in Italy since 1950. *Scienze Regionali. Italian Journal of Regional Science*, 8(3) (Supplement), pp. 11-34.

Calafati, A. G. (2009). *Economie in cerca di città. La questione urbana in Italia*. Rome: Donzelli.

Calafati, A. G., & Veneri, P. (2013). Re-defining the boundaries of major Italian cities. *Regional Studies*, *47*(5), pp. 789-802.

Camagni, R. (1992). *Economia urbana: principi e modelli teorici*, Roma: La nuova Italia.

Camagni, R., Gibelli, M. C., & Rigamonti, P. (2002a). Urban mobility and urban form: the social and environmental costs of different patterns of urban expansion. *Ecological Economics*, *40*(2), pp. 199-216..

Camagni, R., Gibelli, M. C., & Rigamonti, P. (2002b). *I costi collettivi della città dispersa*. Florence: Alinea.

Camagni, R., & Salone, C. (1993). Network urban structures in Northern Italy: elements for a theoretical framework. *Urban Studies*, *30*(6), pp. 1053-1064.

Canton, E. J., de Groot, H. L., & Nahuis, R. (2002). Vested interests, population ageing and technology adoption. *European Journal of Political Economy*, *18*(4), 631-652.

Capello, R. (2000). The City network paradigm: measuring urban network externalities. *Urban Studies*, *37*(11), pp. 1925-1945.

Capello, R., (2007). *Regional Economics*. New York: Routledge.

Capello, R., & Camagni R. (2000). Beyond optimal city size: an evaluation of alternative urban growth patterns. *Urban Studies*, *37*(9), pp. 1479-1496.

Capello, R., Resmini, L., & Fratesi, U. (2011). *Globalization and Regional Growth in Europe. Past Trends and Future Scenarios*. London: Springer.

Cervero, R. (1995). Sustainable new towns: Stockholm's rail-served satellites. *Cities*, *12*(1), pp. 41-51.

Cervero, R. (2001). Efficient urbanisation: economic performance and the shape of the metropolis. *Urban Studies*, *38*(1), pp. 1651-1671.

Cheshire, P. C., & Hay, D. G. (1989). *Urban Problems in Western Europe*, London: Unwin Hyman.

Cheshire, P. C., & Magrini S. (2006). Population growth in European cities: whether matters – but only nationally. *Regional Studies*, *40*(1), pp. 23-37.

Chien, S. S. (2008). The isomorphism of local development policy: a case study of the formation and transformation of national development zones in post-Mao Jiangsu, China. *Urban Studies*, *45*(2), pp. 273-294.

Christaller, W. (1933). *Die zentralen orte in Süddeutschland*, Darmstadt: Wissenschaftlische Buchgesellschaft.

Ciccone, A. (2002). Agglomeration effects in Europe. *European Economic Review*, *46*, pp. 213-227.

Ciccone, A., & Hall, R. E. (1996). Productivity and the density of economic activity. *The American Economic Review*, *86*(1), pp. 54-70.

Cirilli, A., & Veneri, P. (2011). Understanding the determinants of urban growth: a study on the major Italian cities. *Rivista Italiana degli Economisti*, *3*, pp. 477-505.

Clark, G. I. (2001). Vocabulary of the new Europe: code words for the millennium. *Environment and Planning D: Society and Space*, *19*, pp. 697-717.

Coe, N. M., & Townsend, A. R. (1998). Debunking the myth of localized agglomerations: the development of a regionalized service economy in south-east England. *Transactions of the Institute of British Geographers, New series*, 23, pp. 385-404.

Combes, P. P. (2000). Marshall-Arrow-Romer externalities and city growth. *CERAS Working Papers*, n. 99-06.

Combes, P. P., & Overman, H. G. (2004). The spatial distribution of economic activities in the European Union. In Henderson, V., & Thisse, J. F. (eds.), *Handbook of Regional and Urban Economics*, *Vol. 4,* (Ch. 64, pp. 2845-2909). Amsterdam: Elsevier Science.

Commission of the European Communities (1999). *European Spatial Development Perspective. Towards balanced and sustainable development of the territory of the EU*, Postdam: Agreed at the Informal Meeting of Ministers Responsible for Spatial Planning of the Member States of the European Union.

Cox, W. (2013, June 15). The evolving urban form: the Rhine-Ruhr (Essen-Düsseldorf), *New Geography*. Retrieved from http://www.newgeography.com/content/003769-the-evolving-urban-form-the-rhine-ruhr-essen-d-sseldorf

Craig, S., & Ng, P. (2001). Using quantile smoothing splines to identify employment subcenters in a multicentric urban area. *Journal of Urban Economics*, *49*(1), pp. 100–120.

Cutsinger, J., Galster, G., Wolman, H., Hanson, R., & Towns, D. (2005). Verifying the multidimensional nature of metropolitan land use: Advancing the understanding and measurement of sprawl. *Journal of Urban Affairs*, *27*(3), pp. 235-259.

Davoudi, S. (2003). Polycentricity in the European spatial planning: from an analytical tool to a normative agenda. *European Planning Studies*, *11*(8), pp. 979-999.

de Dominicis, L., Arbia, G., & de Groot, H. L. F. (2013). Concentration of manufacturing and service sector activities in Italy: accounting for spatial dependence and firm size Distribution. *Regional Studies*, *47*(3), pp. 27-55.

de Groot, H. L. F., Poot, J., & Smit, M. (2009). Agglomeration externalities, innovation and regional growth: theoretical perspectives and meta-analysis. In Capello, R., & Nijkamp, P. (eds.), *Handbook Of Regional Growth And Development Theories*, Cheltenham, UK: Edward Elgar.

Dieleman, F. M., & Faludi, A. (1998). Polynucleated metropolitan regions in Northwest Europe: theme of the Special Issue. *European Planning Studies*, *6*(4), pp. 365-377.

DiMaggio, P. J., & Powell, W. W. (1983). The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. *American Sociological Review*, *48*, pp. 147-160.

Duranton, G. (2007). Urban evolutions: the fast, the slow, and the still. *The American Economic Review*, *97*(1), pp. 197-221.

Duranton, G., & Puga, D. (2004). Micro-foundations of urban increasing returns: theory. In J.V. Henderson and J.-F. Thisse (eds.), *Handbook of Regional and Urban Economics*, Vol. 4 (pp. 2063-2117). Amsterdam: North Holland,.

Eeckhout, J. (2004). Gibrat's law for (all) cities. *The American Economic Review*, *94*(5), pp. 1429-1451.

Elmaleh, A., Galy, A., Allard, T., Dairon, R. , Day, J.A. , Michel, F., Marriner, N., Morhange, C., & Couffignal F. (2012). Anthropogenic accumulation of metals and metalloids in carbonate-rich sediments: Insights from the ancient harbor setting of Tyre (Lebanon). *Geochimica et Cosmochimica Acta, 82*, pp. 23-28.

European Commission (2007). *Territorial Agenda of the European Union*. *Towards a more competitive and Sustainable Europe of Diverse Regions.* Potsdam.

European Commission (2011). *Territorial Agenda of the European Union 2020. Towards an Inclusive, Smart and Sustainable Europe of Diverse Regions*.

Ewing, R., & Cervero, R. (2010). Travel and the built environment: a meta-analysis. *Journal of the American Planning Association*, *76*(3), pp. 265-294.

Fallah, B. N., Partridge, M. D., & Olfert, M. R. (2011). Urban sprawl and productivity: evidence from US metropolitan areas. *Papers in Regional Science*, *90*(3), pp. 451-472.

Florida, R. (2005). The World is Spiky. *The Atlantic Monthly, 49*, pp. 48-51.

Friedman, J., & Miller, J. (1965). The urban field**.** *Journal of the American Institute of Planners*, *31*(4), pp. 312– 320.

Friedman, T. L. (2005). *The world is flat*. New York: Farrar, Straus and Giroux.

Fiaschi, D., Gianmoena, L., & Parenti, A. (2011). The dynamics of Labour Productivity Across Italian Provinces: Convergence and Polarization. *Rivista Italiana degli Economisti*, *2*, pp. 209-240.

Fujita, M., & Ogawa, H. (1982). Multiple equilibria and structural transition of non-monocentric urban configuration. *Regional Science and Urban Economics*, *12*, pp.161– 196.

Fujita, M., Krugman, P., & Venables, A. J. (1999). *The spatial economy: cities, regions and international trade*. Cambridge, MA and London: The MIT Press.

Gabaix, X. (1999). Zipf 's Law and the Growth of Cities. *The American Economic Review*, *89*(2), pp. 129–132.

Gabaix, X., & Ioannides Y. (2004). The evolution of city size distribution. In Henderson, V., & Thisse, J. F. (eds.). *Handbook of Regional and Urban Economics*, Vol. 4 (Chapter 53, pp. 2341-2378), Amsterdam: Elsevier Science.

Galster, G., Hanson, R., Ratcliffe, M. R., Wolman, H., Coleman, S., & Freihage, J. (2001). Wrestling sprawl to the ground: defining and measuring an elusive concept, *Housing Policy Debate*, *12*, pp. 681-717.

Garreau, J. (1991). *Edge cities: Life on the new frontier*. New York: Doubleday.

Geddes, P. (1915). *Cities in evolution: an introduction to the town planning movement and to the study of civics*. London: Williams & Norgate.

Gill, I.S., & Goh, C.C. (2010). Scale economies and cities. *The World Bank Research Observer*, *25*(2), pp. 235-262.

Giuliano, G., & Small, K. (1991). Subcenters in the Los Angeles region. *Regional Science and Urban Economics*, *21*(2), pp. 163–182.

Glaeser, E. L. (1998). Are Cities Dying?. J*ournal of Economic Perspectives*, *12*(2), pp. 139–160.

Glaeser, E. L. (2011). *Triumph of the city: how our greatest invention makes us richer, smarter, greener, healthier, and happier*. New York: Penguin.

Glaeser, E. L., & Gottlieb, J. D. (2009). The wealth of cities: agglomeration economies and spatial equilibrium in the United States. *Journal of Economic Literature*, *47*(4), pp. 983-1028.

Glaeser, E. L., & Kahn, M. E. (2001). Decentralized employment and the transformation of the American city. *Brookings-Wharton Papers on Urban Affairs*, pp. 1-63.

Glaeser, E. L., Kahn, M. E. (2004). Sprawl and urban Growth. In Henderson, V., & Thisse, J. F. (eds.). *Handbook of Regional and Urban Economics*, Vol. 4 (Chapter 56, pp. 2481-2527). Amsterdam: Elsevier Science.

Glaeser, E. L., Kahn, M. E., & Chu, C. (2001). *Job sprawl: employment location in U.S. Metropolitan Areas*. Washington, DC: Brookings Institution Press.

Glaeser, E. L., Kallal, H. D., Scheinkman, J. A., & Shleifer A. (1992), Growth in cities. *The Journal of Political Economy*, *100*(6), pp. 1126–1152.

Gobillon, L., Selod, H., & Zenou, Y. (2007). The mechanisms of spatial mismatch. *Urban Studies*, *44*(12), pp. 2401-2427.

de Goei, B., Burger, M., Kitson, M., & van Oort, F. (2008). Polycentric urban configurations and urban network development in the Greater South East UK 1981-2001. *Research Bulletin 268, GaWC*, Loughborough.

Gordon, P., Kumar, A., & Richardson, H. V. (1989). The influence of metropolitan spatial structure on commute time. *Journal of Urban Economics*, *26*(2), pp. 138–151.

Gordon, P., & Richardson, H. W. (1989). Gasoline consumption and cities: a reply. *Journal of the American Planning Association*, *55*(3), pp. 342-346.

Gordon, P., & Richardson, H. W. (1996). Beyond polycentricity: the dispersed Metropolis, Los Angeles, 1970-1990. *Journal of the American Planning Association*, *62*(3), pp. 289-295.

Gordon, P., Richardson, H.V., & Wong, W. (1986). The distribution of population and employment in a polycentric city: the case of Los Angeles. *Environment and Planning*, *18*(2), pp. 161–173.

Gottmann, J. (1961). *Megalopolis. The urbanized north eastern seaboard of the United States*, New York: the Twentieth Century Fund.

Governa, F., & Salone, C. (2005). Italy and European spatial policies: polycentrism, urban networks and local innovation. *European Planning Studies*, *13*(2), pp. 265–283.

Graham, D. J., Melo, P. S., Jiwattanakulpaisarn, P., & Noland, R. B. (2010). Testing for causality between productivity and agglomeration economies. *Journal of Regional Science*, *50*(5), pp. 935-951.

Grassmueck, G., & Shields, M. (2010). Does government fragmentation enhance or hinder metropolitan economic growth?. *Papers in Regional Science*, *89*(3), pp. 641-658.

Green, N. (2007). Functional polycentricity: a formal definition in terms of social network analysis. *Urban Studies*, *44*(11), pp. 2077-2103.

Grubel, H. G., & Lloyd, P. J. (1975). *Intra-industry trade: the theory and measurement of international trade in differentiated products (Vol. 205)*. London: Macmillan.

Hague, C., & Kirk, K. (2003). *Polycentricity scoping study*, London: Office of the Deputy Prime Minister.

Hall, P. (1993). Forces shaping urban Europe. *Urban Studies*, *30*(6), pp. 883–898.

Hall, P. (2009). Polycentricity. In Kitchin, R., & Thrift, N. (eds.), *The International Encyclopedia of Human Geography*, Vol. *8* (pp. 260-264). Oxford: Elsevier.

Hall, P., & Hay, D.G. (1980). *Growth Centres in the European Urban System.* London: Heinemann Educational.

Hall, P., & Pain, K. (eds.) (2006). *The polycentric Metropolis. Learning from Mega-City regions in Europe,* London: Earthscan.

Harris, C. D., & Ullman E. L. (1945). The nature of cities. *Annals of the American Academy of Political and Social Science*, *242*, pp. 7-17.

Hawken, P., Lovins, A., & Lovins, L. H. (1999). *Natural Capitalism: Creating the Next Industrial Revolution*. London: Routledge.

Henderson, J.V. (1974). Sizes and types of cities. *The American Economic Review*, *64*(4), pp. 640-656.

Hohenberg, P.M., & Lees, L.H. (1985). *The making of Urban Europe*. Cambridge, Mass: Harvard University Press.

Houghton, R. A., House, J. I., Pongratz, J., van der Werf, G. R., DeFries, R. S., Hansen, M. C., Le Quéré, C., & Ramankutty, N. (2012). Carbon emissions from land use and land-cover change. *Biogeosciences*, *9*(12).

IGEAT (2007). *ESPON 1.4.3: Study on Urban Functions. Final Report. Technical report*. Luxembourg: European Spatial Planning Observation Network.

IRPET (1975). *Lo Sviluppo Economico della Toscana*. Firenze: Guaraldi.

ISPRA (2014). *Italian Greenhouse Gas Inventory 1990-2012, National Inventory Report 2014*. Roma.

ISPRA (2014). *Il consumo di suolo in Italia*. Roma.

Jacobs, J. (1969). *The economy of cities*. New York: Random House

Johansson, B., & Lambregts, B. (2004). Agglomeration and networks in spatial economies. In Florax, R., & Plane, D. (eds.), *Fifty years of Regional Science* (pp. 165-176), Springer.

Johnson, M. P. (2001). Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. *Environment and Planning A*, *33*(4), pp. 717–735.

Jones, H. L., (1930). *The Geography of Strabo with an English translation*, VII, The Loeb Classical Library. Cambridge, Mass.: Harvard University Press, & London: William Heinemann Ltd.

Kelejian, H. H., & Prucha, I. R. (1998). A generalized spatial two stage least squares procedure for estimating a spatial autoregressive model with autoregressive disturbances. *Journal of Real Estate Finance and Economics*, *17*, pp. 99-121.

Kloosterman, R., & Lambregts, B. (2001). Clustering of economic activities in Polycentric Urban Regions: the case of the Randstad. *Urban Studies*, *38*(4), pp. 717–732.

Kloosterman, R., & Musterd S. (2001). The Polycentric Urban Region: towards a research agenda. *Urban Studies*, *38*(4), pp.623–633.

Krugman, P. (1991). *Geography and trade*. Cambridge, MA: MIT Press.

Krugman, P. (1995). *Development, geography and economic theory*. Cambridge, MA: MIT Press.

Lambooy, J. (1998). Polynucleation and economic develoment: the Randstad. *European Planning Studies*, *6*(4), pp. 457–466.

Lang, R. E. (2003). *Edgeless Cities: Exploring the Elusive Metropolis*, Washington, D.C.: Brookings Institution Press.

Lee, B. (2007). "Edge" or "Edgeless" Cities? Urban Spatial Structure in U.S. Metropolitan Areas, 1980 to 2000. *Journal of Regional Science*, *47*, pp. 479-515.

Lee, B., & Gordon, P. (2011). Urban Spatial Structure and Economic Growth in US Metropolitan Areas. *Journal of Regional Science*, forthcoming.

Lee, B., & Gordon, P. (2011). Urban structure: its role in urban growth, net new business formation and industrial churn. *Région et Developpement*, *33*, pp. 137-159.

LeRoy, S. F., & Sonstelie, J. (1983). Paradise lost and regained: Transportation innovation, income, and residential location. *Journal of Urban Economics*, *13*(1), pp. 67-89.

Limtanakool, N., Dijst, M., & Schwanen, T. (2007). A theoretical framework and methodology for characterizing National urban systems on the basis of flows of people: empirical evidence for France and Germany. *Urban Studies*, *44*(11), pp. 2123-2145.

Limtanakool, N., Schwanen, T., & Dijst, M. (2009). Developments in the Dutch Urban Systems on the Basis of Flows, *Regional Studies 43*(2), pp. 179–196.

Limtanakool, N., Schwanen, T., & Martin, M. (2007). Ranking Functional Urban Regions: a Comparison of Interaction and Node Attribute Data. *Cities*, *24*(1), pp. 26–42.

Lösch, A. (1940). *Die Räumlische Ordnung der Wirtshaft*, Jena: Gustav Fisher.

Lösch, A. (1954). *The Economics of Location*, New Haven, Conn., Yale University Press.

Lucas, R. E. (1988). On the mechanisms of economic development. *Journal of Monetary Economics*, *25*(1), pp. 3-42.

Malanima, P. (2005). Urbanisation and the Italian Economy During the Last Millennium. *European Review of Economic History*, *9*, pp.97–122.

Marshall, A. (1890). *Principles of Economics*. London: Macmillan.

Matthews, E., & Hutter, C. (eds.), (2000). *The weight of nations*. World Resources Institute, available on line at http://www.wri.org/publication/weight-nations

Mc Millen, D.P., & Smith, S.C. (2003). The Number of Subcenters in Large Urban Areas. *Journal of Urban Economics*, *53*(3), pp. 321-338.

Meijers, E. (2007). Clones or complements? The division of labour between the main cities of the Randstad, the Flemish Diamond and the Rhein Ruhr Area. *Regional Studies 41*(7), pp. 889–900.

Meijers, E. (2008). Measuring polycentricity and its promises. *European Planning Studies*, *16*(9), pp. 1313-1323.

Meijers, E., & Sandberg, K. (2006). Polycentric development to combat regional disparities? the relation between polycentricity and regional disparities in European countries. *ERSA conference papers ersa06p287*, European Regional Science Association.

Meijers, E., & Sandberg, K. (2008). Reducing regional disparities by means of polycentric development: panacea or placebo?. *Scienze Regionali – Italian Journal of Regional Science*, *7*(2) (Suppl.), pp. 71-96.

Meijers, E., & Burger, M. J. (2010). Spatial structure and productivity in US metropolitan areas. *Environment and Planning A*, *42*, pp.1383-1402.

Mills, Edwin S. (1972). *Studies in the Structure of the Urban Economy*. Baltimore: Johns Hopkins Press.

Mitchell, G., Hargreaves, A., Namdeo, A., & Echenique, M. (2011). Land use, transport, and carbon futures: the impact of spatial form strategies in three UK urban regions. *Environment and Planning-Part A*, *43*(9), p. 2143.

Mulligan, G. F. (1984). Agglomeration and central place theory: a review of the literature. *International Regional Science Review*, *9*, pp. 1-42.

Muñiz, I., García López, M.A., & Calatayud, D. (2006). SPRAWL. Definición, causas y efectos, *Working Papers*. Department of Applied Economics, Universitat Autónoma de Barcelona.

Muth, Richard F. (1969). *Cities and Housing*. Chicago: University of Chicago Press

Nechyba, T. J., & Walsh, R. P. (2004). Urban sprawl. *Journal of economic perspectives*, *18*(4), pp. 177-200.

Newman P., & Kenworthy J. (1989). *Cities and Automobile Dependence: An International Sourcebook*, Aldershot: Gower.

Newman, P., & Kenworthy, J. (1999). *Sustainability and cities: overcoming automobile dependence*. Island Press.

Newman, P. (2006). The environmental impact of cities. *Environment and Urbanization*, *18*(2), pp. 275–295.

Nijkamp, P. Ed. (1986). *Handbook of Regional and Urban Economics*, vol. I: *Regional Economics*, Amsterdam: North-Holland.

Nordregio (2004*). ESPON 1.1.1: Potentials for Polycentric Development in Europe. Project Report*. Technical report, European Spatial Planning Observation Network.

OECD (2009a). *How regions grow*. Paris: Organisation for Economic Growth and Development

OECD (2009b). *Regions Matter: Economic Recovery, Innovation and Sustainable Growth*. Paris: Organisation for Economic Growth and Development

OECD (2011). *Regional Outlook*. Paris: Organisation for Economic Growth and Development.

OECD (2012). *Compact city policies. A comparative assessment*, OECD Green Growth Studies, Paris: Organisation for Economic Growth and Development.

Oke, T. R. (1973). City size and the urban heat island. *Atmospheric Environment*, *7*(8), pp. 769-779.

Openshaw, S., Taylor, P. J. (1979). A million or so correlation coefficients: three experiments on the Modifiable Area Unit Problem. In Wrigley, N. (ed.), *Statistical Applications in the Spatial Sciences*. London: Pion. Pp. 127-144.

Orfield, M. (1997). *Metropolitics: A Regional Agenda for Community and Stability.* Washington, DC: Brookings Institution, and Cambridge, MA: Lincoln Institute of Land Policy.

Owen, D. (2010). *Green Metropolis: Why Living Smaller, Living Closer, and Driving Less Are the Keys to Sustainability*. New York: Riverhead.

Paci, R., & Pusceddu, N. (2000). Stima dello stock di capitale nelle regioni italiane. *Rassegna Economica*, *Quaderni di Ricerca*, pp. 97-118.

Parr, J. B., (1979). Regional economic change and regional spatial structure: some interrelationships. *Environment and Planning A*, *11*(7), pp. 825 – 837

Parr, J. B. (1985). A note on the size distribution of cities over time. Journal of Urban Economics, *18*, pp. 199-212.

Parr, J. B. (1987). The Development of Spatial Structure and Regional Economic Growth. *Land Economics*, *63*(2), pp. 113-112

Parr, J. B. (2002). Agglomeration economies: ambiguities and confusions. *Environment and Planning A*, *34*, pp. 717-731.

Parr, J. B. (2004). The polycentric urban region: A closer inspection. *Regional Studies*, *38*(3), pp. 231-240.

Parr, J. B. (2007). Spatial definitions of the city: four perspectives. *Urban studies*, *44*(2), pp. 381-392.

Perkins, A., Hamnett, S., Pullen, S., Zito, R., & Trebilcock, D. (2009). Transport, housing and urban form: the life cycle energy consumption and emissions of city centre apartments compared with suburban dwellings. *Urban Policy and Research*, *27*(4), pp. 377-396.

Pietrobelli, C. (1998). The socio-economic foundations of competitiveness: an econometric analysis of Italian Industrial Districts. *Industry and Innovation*, *5*(2), pp. 139-155.

Porter, M. E. (1990*)*. *The Competitive Advantage of Nations*. New York: Free Press.

Poumanyvong, P., & Kaneko, S. (2010). Does urbanization lead to less energy use and lower CO2 emissions? A cross-country analysis. *Ecological Economics*, *70*, pp. 434-444.

Priemus, H. (1994). Planning the Randstad: Between Economic Growth and Sustainability. *Urban Studies*, *51*(12), pp. 509–534.

Puga, D. (2010). The magnitude and causes of agglomeration economies. *Journal of Regional Science*, *50*(1), pp. 203-219.

Rickwood, P., Glazebrook, G., & Searle, G. (2008). Urban structure and energy—a review. *Urban policy and research*, *26*(1), pp. 57-81.

Riguelle, F., Thomas, I., & Verhetsel, A. (2007). Measuring urban polycentrism: a European case study and its implications. *Journal of Economic Geography* , *7*(2), pp. 193-215.

Roca Cladera, J., Marmolejo Duarte, C. R., & Moix, M. (2009). Urban structure and polycentrism: towards a redefinition of the sub-centre concept. *Urban Studies*, *46*(13), pp. 2841-2868.

Rodriguez, D. A., Targa, F., & Aytur, S. A. (2006). Transport implications of urban containment policies: a study of the largest twenty-five US metropolitan areas. *Urban Studies*, *43*(10), pp. 1879-1897.

Rosenthal, S., Strange, W. C. (2004). Evidence on the nature and sources of agglomeration economies. In Henderson, J.V., Thisse J.F. (eds.). *Handbook of Regional and Urban Economics* (Ch. 49, pp. 2119-2171), Amsterdam: Elsevier,.

Schmitt, P. (2011). The Territorial Agenda of the European Union 2020 – A turning point in striving for Territorial Cohesion*?. Nordregio News Publication*, *1*, pp. 3-8.

Sforzi, F. (1990). The quantitative importance of Marshallian industrial districts in the Italian economy. In Pyke, F., Becattini, G., Sengenberger, W. (eds.). *Industrial districts and interfirm cooperation in Italy*, pp. 75-107.

Smith, A. (1776). An Inquiry into the nature and causes of the wealth of Nations. London: Printed for W. Strahan, and T. Cadell.

Sohn, J. (2005). Are Commuting Patterns a Good Indicator of Urban Spatial Structure?. *Journal of Transport Geography*, *13*, pp. 306–317.

Stern, N. (2008). The economics of climate change. *The American Economic Review*, 98(2), pp. 1-37.

Storper, M., & Venables, A. J. (2004). Buzz: face-to-face contact and the urban economy. *Journal of Economic Geography*, *4*(4), pp. 351-370.

Travisi, C. M., Camagni, R., & Nijkamp, P. (2010). Impacts of urban sprawl and commuting: a modelling study for Italy. *Journal of Transport Geography*, *18*(3), pp. 382-392.

Tsai, Y. (2001.) *Travel-Efficient Urban Form: a Nationwide Study on Small Metropolitan Areas*, PhD Thesis, University of Michigan, Ann Arbor, MI.

Tsai, Y.-H. (2005), Quantifying Urban Form: Compactness versus 'Sprawl', *Urban Studies*, *42*(1), 141-161.

Vandermotten, C., Roelandts, M., & Cornut, P. (2007). European polycentrism: towards a more efficient and/or more equitable development?. In Cattan, N. (ed.), *Cities and networks in Europe. A critical approach of polycentrism,* Montrouge: John Libbey Eurotext.

Vandermotten, C., Halbert, L., Roelandts, M., & Cornut, P. (2008). European Planning and the Polycentric Consensus: Wishful Thinking?". *Regional Studies*, *42*(8), pp. 1205-1217.

Van der Laan, L. (1998). Changing urban systems: an empirical analysis at two spatial levels. *Regional Studies*, *32*(3), pp. 235-247.

Van Houtum, H., & Lagendijk, A. (2001). Contextualising regional identity and imagination in the construction of polycentric urban regions: the cases of the Ruhr area and the Basque country. *Urban Studies*, *38*(4), pp. 747-767.

Van Soest, D. P., Gerking, S., & Van Oort, F.G. (2006). Spatial impacts of agglomeration externalities. *Journal of Regional Science*, *46*, pp. 881–899

Veneri, P. (2010). Urban Polycentricity and the Costs of Commuting: Evidence from Italian Metropolitan Areas. *Growth and Change*, *41*(3), pp. 403–429.

Veneri, P. (2013). *On City Size Distribution: Evidence from OECD Functional Urban Areas*, OECD Regional Development Working Papers, 27, Paris.

Waterhout, B., Zonneveld, W., & Meijers, E. (2005). Polycentric development policies in Europe: overview and debate. *Built Environment*, *31*(2), pp. 163–173.

Wheaton, W. C. (2004), Commuting, Congestion, and Employment Dispersal in Cities with Mixed Land Use. *Journal of Urban Economics*, *55*, pp. 417–438.

White, M. J. (1999). Urban areas with decentralized employment: theory and empirical work. In Cheshire, P., & Mills E.S. (Eds). *Handbook of Regional and Urban Economics. Vol. 3: Applied Urban Economics*, (pp. 1375-142), Amsterdam: North-Holland.

World Bank (2009). *World Development Report 2009: Reshaping Economic Geography*. Washington DC.