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

David Burgalassi [a,*], Tommaso Luzzati [b]

[a] IRPET (Regional Institute for Economic Planning of Tuscany), via P. Dazzi 1, 50141 Firenze, Italy
[b] University of Pisa, Department of Economics and Management, via Ridolfi 10, 56124 Pisa, Italy

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ABSTRACT

This paper addresses the relationship between urban spatial structure and emissions. 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 residential heating. Our 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.

1. Aims

Far from being confined to the modern era, environmental crises often occurred in more remote times. Such crises concerned not only resource management (e.g., the well-known and widely studied case of Easter Island) but also pollution. For instance, starting more than 2000 years ago, purple-dye production had a major environmental impact 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 transport and process huge amounts of matter (e.g., Matthews & Hutter, 2000), greatly increasing not only their prosperity but also the environmental impacts concerned. 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.

Energy abundance also led to urban development. In the Neolithic, improvements in agriculture and in stock breeding resulted in energy surpluses that made it possible for a larger share of the population to be released from food production, which in turn led to the emergence of the city (e.g., Glaeser, 2011, p. 168; Mumford, 1956). Again, with the radical change in energy availability, the industrial revolution involved a rapid growth in urbanisation, due both to population growth and to migration from the countryside, a process that is still occurring in emerging countries.

Again, energy has been a major factor behind structural changes occurring in urban areas in recent decades (Anderson, Kanaroglou, & Miller, 1996, p. 12), since "cheap" energy made transports quicker, cheaper and more convenient, making it easier to reside away from urban cores. This has led to urban sprawl, such that "the contemporary city has no clear boundaries; it is a city of dissipated activities and changeable links" (Bertolini, 2012, p. 18). Urban sprawl makes evident the links between energy abundance, spatial organisation of human settlements, and environmental pressures, both at the local and global level. For instance, Bart (2010) analysed the relationship between trends in transport emissions and urban land use, finding a strong correlation between transport CO_2 emissions and the increase in artificial land area.

The present investigation aims to explore the role of spatial structure in the Italian case, focusing on private transport and residential energy consumption and the CO_2 and PMs emissions involved. First (Section 2), by surveying the most relevant literature, we set out the theoretical frame and illustrate the current empirical evidence. Then (Sections 3 and 4) we move on to empirical analysis and test whether the theoretical intuitions hold for Italy, analysing its provinces (NUTS 3 spatial level).

* Corresponding author.
E-mail addresses: david.burgalassi@irpet.it (D. Burgalassi), tommaso.luzzati@unipi.it (T. Luzzati).

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Italy provides an interesting case study, since, like other advanced countries, it shows pronounced phenomena of urbanisation and suburbanisation. To be precise, in the 1950s Italy's urbanised areas covered 8700 km^2 (178 m^2 per capita) rising to 21,900 km^2 in 2012 (370 m^2 per capita) (ISPRA, 2014a, 2014b). Moreover, as in other European countries (Anas, Arnott, & Small, 1998), Italian urban evolution has been path-dependent, that is, urban areas and conurbations have emerged from the coalescence of previous existing centres (Calafati, 2012).

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 to examine the possible causal links between spatial structure and emissions.

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 & Reynolds, 1971, p. 36). As often highlighted (see, e.g., Lee, 2006, p. 9) urban spatial structure is the resultant of the distribution of residential 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: form and interactions together give rise to spatial structure (Bourne, 1982).

Urban centres are key elements in the regional structure and its development. Being characterised by the concentration of economic activity, such centres represent the economic core of spatial systems, providing functions for the rest of the region. Urbanisation has promoted agglomeration economies (Glaeser, Kallal, Scheinkman, & Shleifer, 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).

The dynamics of human settlements, both in time and space, can usefully be described by referring to the changing roles of urban centres and of the territories around them. In some instances regions are organised around a main centre, in other we observe several interconnected centres, while the degree of urbanisation and patterns around centres may considerably differ (Camagni, Gibelli, & Rigamonti, 2002). Although we acknowledge the multi-faceted nature of the concept of spatial structure, herein we follow Meijers and Burger (2010) by focusing only on urban dispersion and polycentricity, two concepts that, despite their interrelationships (Gordon & Wong, 1985, p. 662; Bertaud, 2004), need to be kept distinct.

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, there are 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 have often moved regional structure towards dispersion rather than concentration, generating so-called "urban sprawl" (Fig. 1).

By the mid 20th century urban dispersion had increased considerably in North America due to the revolution of mass motorisation (Burchfield, Overman, Puga, & Turner, 2006). Commuting became cheaper and easier, allowing more freedom in the choice of residential location. People no longer needed to live close to their workplace or commercial activities and started to relocate out from city cores. Residential relocation first involved the upper income classes, who initially could afford the use of private vehicles, and then, with the decline in transport costs, also low income households were attracted by the cheaper land prices of the surroundings (Le Roy & Sonstelie, 1983). Cheap land prices also encouraged extensive land use around the new settlements. Similar dynamics appeared later on in Europe and other areas, where urban growth has come together with urban sprawl in recent decades, especially in the most advanced regions and in areas of 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, p. 17). Urban sprawl has been approached by different disciplines and points of view (Arribas-Bel, Nijkamp, & Scholten, 2011; Frenkel & Ashkenazi, 2008) resulting in a large body of literature. As a consequence, there is no widely accepted definition and measure for it (Chin, 2002; Galster et al., 2001). However, the commonly shared idea is that urban sprawl relates to patterns of "excessive" geographical expansion of urban settlements (Brueckner, 2000), entailing sub-optimal land use. In static terms, this means that the distribution of economic activities across space is mainly characterised 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, Camagni, & Nijkamp, 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) and Bertaud (2004), net density is a better indicator, that is density calculated with respect to the land that can be used, so-called developable land.[1] We proxied developable land with land actually used for artificial purposes as provided by remote-sensing data (Burchfield et al., 2006).

2.1.2. Polycentricity

Polycentricity refers to balanced hierarchical relationships among centres in a regional system, occurring when most 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 importance as compared with the main centre.

There are many approaches to define and measure polycentricity within urban regions (Meijers & Burger, 2010). One approach considers morphological aspects, while another 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 conceptualises hierarchy in terms of interactions among centres (Green, 2007).

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

$$\ln(s) = \alpha + \beta \ln(r) \quad (1)$$

[1] "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, p. 688).