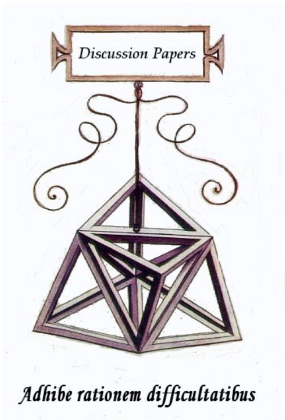
Discussion Papers
Collana di
E-papers del Dipartimento di Economia e Management – Università di Pisa



David Burgalassi
Tommaso Luzzati

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

Discussion Paper n. 199

2015

Discussion Paper n. 199, presentato: **Giugno 2015**

Indirizzo dell'Autore:

David Burgalassi
Istituto Regionale di Programmazione Economica della Toscana, via P. Dazzi 1, 50141 FIRENZE – Italy
tel. (39 +) 055 4591297
fax: (39 +) 055 4591240
Email: david.burgalassi@irpet.it
web site: www.irpet.it

Tommaso Luzzati
Dipartimento di Economia e Management, via Ridolfi 10, 56100 PISA – Italy
tel. (39 +) 050 2216 329
fax: (39 +) 050 598040
Email: tommaso.luzzati@unipi.it
web site: www.ec.unipi.it

Ringraziamenti

Gli autori ringraziano i partecipanti alla conferenza "Structural change, dynamics and economic growth" (Livorno, 13 settembre 2013) per gli utili spunti. Un ringraziamento particolare va a Roberto Camagni, Henri De Groot, Paolo Veneri e Angela Parenti per i preziosi suggerimenti. Ogni errore resta responsabilità degli autori.

Si prega di citare così:
Burgalassi D., Luzzati T. (2015), "Urban spatial structure and environmental emissions: a survey of the literature and some empirical evidence for Italian NUTS-3 regions", Discussion Papers del Dipartimento di Economia e Management – Università di Pisa, n. 100 (http://www-dse.ec.unipi.it/ricerca/discussion-papers.htm).

Discussion Paper
n. 199

David Burgalassi and Tommaso Luzzati

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

Abstract

This paper addresses the relationship between urban spatial structure and emissions. By surveying the most relevant literature, firstly we discuss the concept of spatial structure, focusing in particular on polycentricity and dispersion, 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 that polycentricity reduces emissions.

Classificazione JEL: R12, R14, Q53

Keywords: Urban spatial structure; polycentricity; urban sprawl; emissions; road transport; residential heating.

Indice

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 2), by surveying the most relevant literature, we set the theoretical frame and illustrate the current empirical evidence. Then (in sections 3 and 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).

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.

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.

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 1).

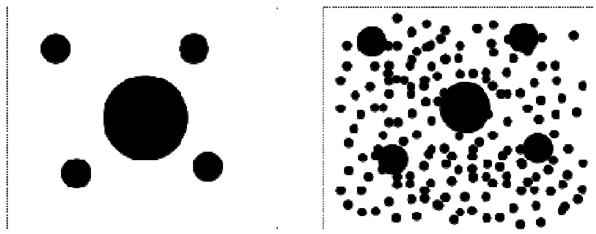


Figure 1: Centralized and dispersed regions

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, 2006). 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[1]. We proxy 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 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:

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

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[2].

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:

[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, 688).

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

$$P_{SF} = (1 - \sigma/\sigma_{\max})\Delta \tag{2}$$

where σ is the standard deviation of the "nodal degree"[3] (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.

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[4]. Although some authors analysed both sectors together[5], most studies focus separately on each of the two aspects.

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, we have a predominance of car journeys and high

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

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

[5] 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.

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[6] — 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.[7]

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,[8] 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).[9] 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 thought to compensate for the increasing distances characterising urban sprawl (Hawke et al., 1999).

---

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

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

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

[9] 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).

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.

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 2 provides a synthetic overview of the links, illustrated in this section, between spatial structure and emissions.

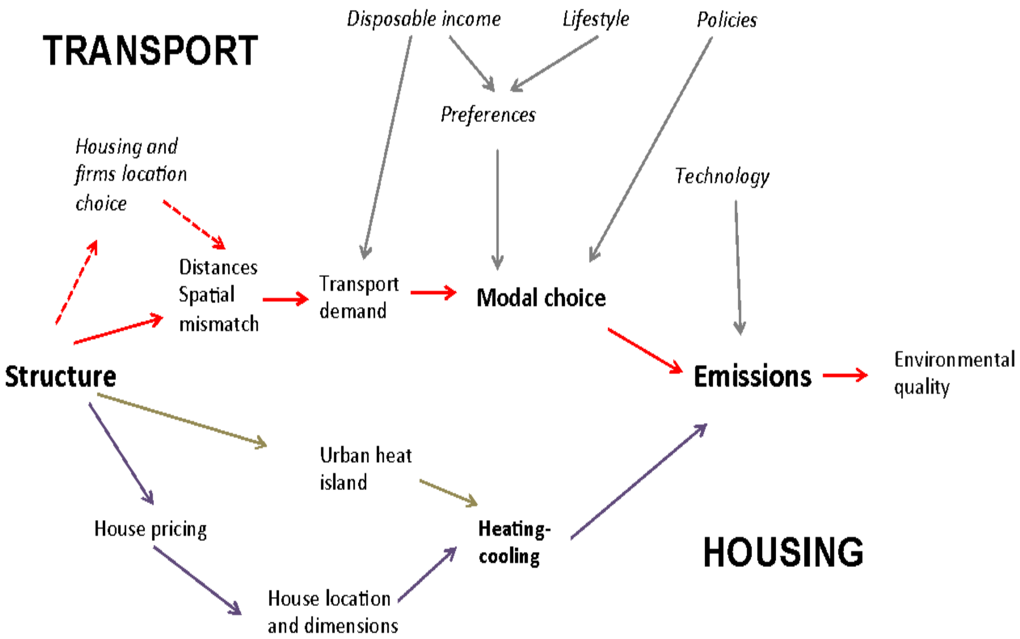


Figure 2: Links between spatial structure and emissions

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,[10] summarise the recent emission trends of CO_2 and PM_{10} in Italy, both total and disaggregated according to the originating sector (SNAP classification). Figure 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 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.

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

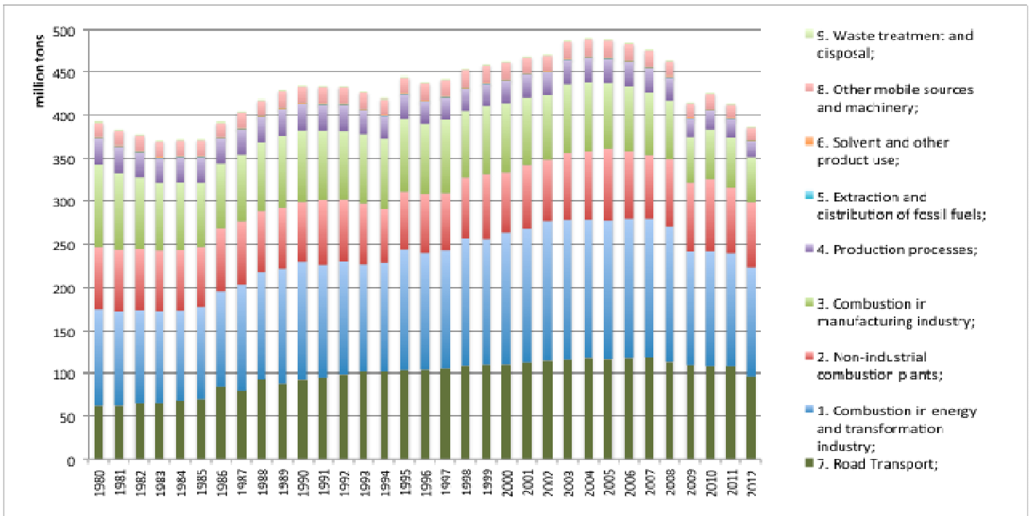


Figure 3: CO_2 in Italy from 1980 to 2012.
Source: ISPRA (Sinanet)

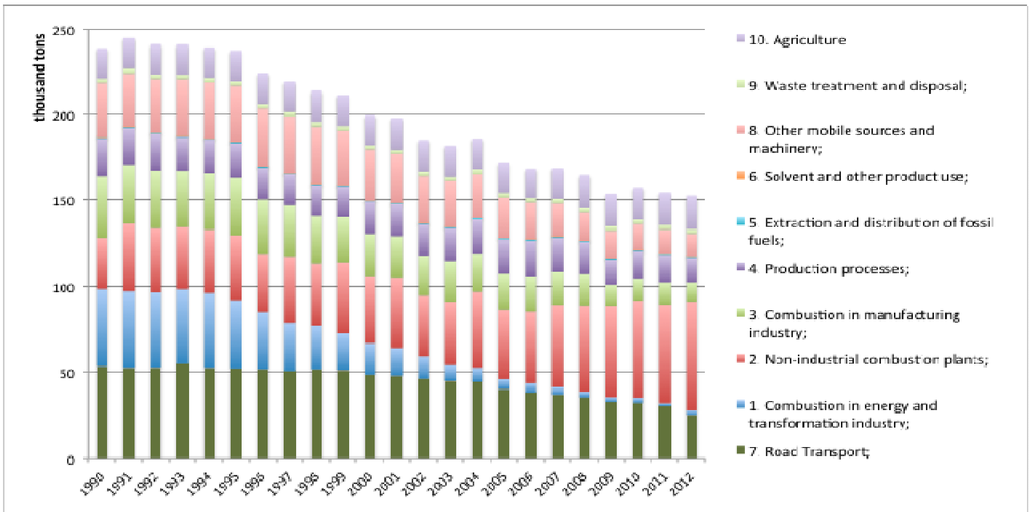


Figure 4: PM_{10} in Italy from 1990 to 2012.
Source: ISPRA (Sinanet)

Table 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 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 2).

Table2: 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 5, by zooming on the lowest bars of Figure 5, 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.

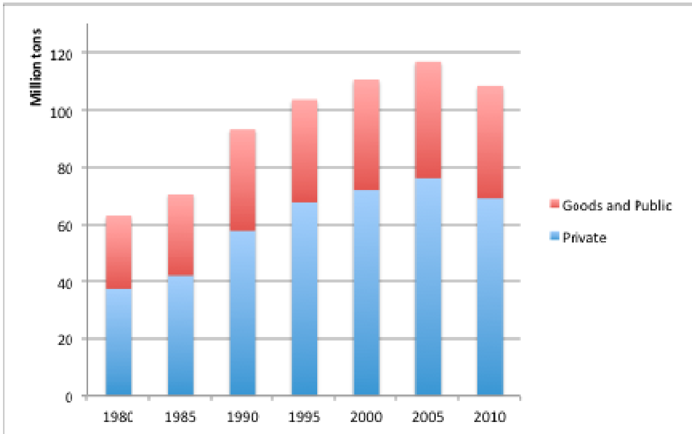


Figure 5: CO_2 emissions from transport, private vs. goods and public transport
Source: Own elaboration on ISPRA-SINANET data

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 6) is considerably higher in the second half of the 2000s, despite the average number of travels remained stable (Figure 7).
Figure 6 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.

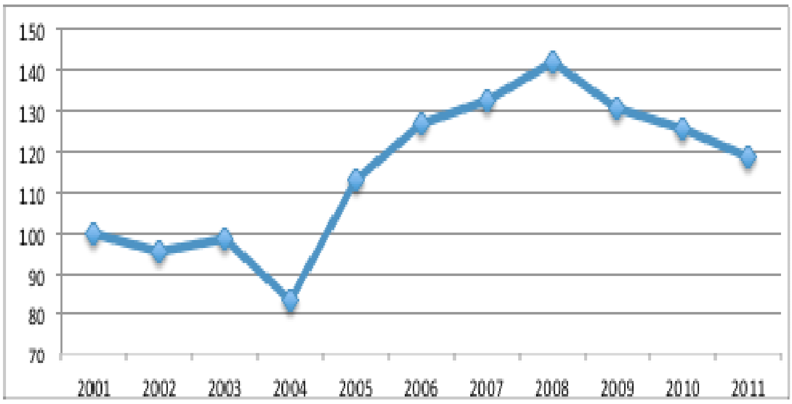


Figure 6: Evolution of passengers*km in a working day
(Source: ISFORT, 2011)

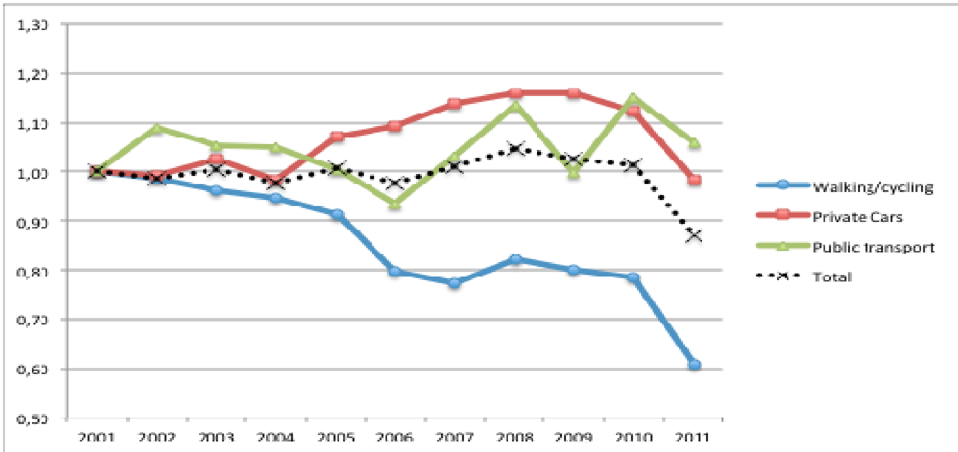


Figure 7: The evolution of modal choices in Italy: the index numbers of the average number of travels in a working day, 2001-2011
(Source: ISFORT, 2011)

Also for residential emissions, trends differ between CO_2 and PM_{10} (see Figure 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.

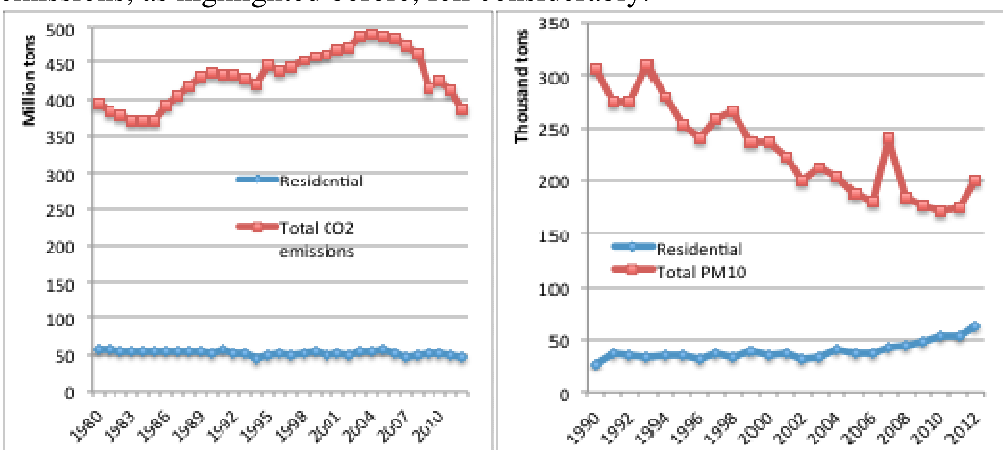


Figure 8: CO_2 and PM_{10} emissions trends - total and residential sector

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.

4.1 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.[11] Dispersion indexes have been calculated by using both population and land use data. The latter have been retrieved from CORINE Land Cover maps provided by EEA.[12]
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[13]. We also included several control variables, as shown in Table 3.

Table3: 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[14]
Public transport accessibility	ESPON Database[15]
House age and number of rooms	ISTAT Census
Surface and altitude	ISTAT Census
Cool days	Italian decrees[16]

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

[12] http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-1990-raster-2
http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-raster-2
http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2

[13] 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.

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

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

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

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[17], land cover data for 1990, 2000 and 2006[18].

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.

4.2 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 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). [19]

More evidence is found for emissions from transport sector. Table 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.

[17] 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.

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

[19] CO_2 emissions might be affected (10% sign. level) either by morphological polycentricity (absolute terms) or by sprawl (per capita terms). See appendix, Table A.5 and Table A.6).

Table 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.	+ ***

5. Conclusions

The aim of this paper was to contribute to the debate about the links between spatial structure and emissions from private transport and residential heating. The literature that was surveyed in section 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.

Bibliography

Anas, A., Arnott, R., & Small, K. A. (1998). *Urban spatial structure*. Journal of economic literature, *36 (3)*, 1426-1464.

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)*, 7-35.

Arribas-Bel, D., Nijkamp, P., & Scholten, H. (2011). Multidimensional urban sprawl in Europe: A self-organizing map approach. *Computers, environment and urban systems*, *35*(4), 263-275.

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.

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), 283–292.

Bertolini, L. (2012). Integrating Mobility and Urban Development Agendas: a Manifesto. *disP-The Planning Review*, *48*(1), 16-26.

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), 466-478.

Bourne, L. S. (1982). *Internal structure of the city: readings on urban form, growth, and policy*. Oxford University Press, USA.

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

Calafati, A. G. (Ed.). (2012). *Le città della terza Italia. Evoluzione strutturale e sviluppo economico*. Milan: FrancoAngeli.

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

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

Childe, V.G. (1954). Early forms of society. in Singer, C., Holmyard, E.J., Hall, A.R. (eds) (1954). *A history of technology*. Oxford: Clarendon Press.

Chin, N. (2002). Unearthing the roots of urban sprawl: a critical analysis of form, function and methodology. *Centre for Advanced Spatial Analysis Working Papers*, 47, University College London.

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

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.

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, 23-28.

European Environment Agency (2006). Urban sprawl in Europe: the ignored challenge. *EAA Report*, *10(*2), 2006.

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

Ewing, R., & Rong, F. (2008). The impact of urban form on US residential energy use. *Housing Policy Debate*, *19*(1), 1-30.

Frenkel, A., & Ashkenazi, M. (2008). Measuring urban sprawl: how can we deal with it?. *Environment and Planning B: Planning and Design*, 35(1), 56.

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*. NY: Doubleday.

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.

Glaeser, E. L., & Kahn, M. E. (2004). Sprawl and urban growth. *Handbook of regional and urban economics*, *4*, 2481-2527.

Glaeser, E. (2011). *Triumph of the city: How our greatest invention makes US richer, smarter, greener, healthier and happier*. Pan Macmillan.

Gordon, P., & Wong, H. L. (1985). The costs of urban sprawl: some new evidence. *Environment and planning A*, *17*(5), 661-666.

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

Green, N. (2007). Functional Polycentricity : A Formal Definition in Terms of Social Network Analysis, *Urban Studies*, *44*(11), 2077–2103.

Hawken, Paul, Lovins A., & Lovins L. H. (1999). *Natural Capitalism: Creating the Next Industrial Revolution*. Little and Brown and Company.

Holden, E., & Norland, I. T. (2005). Three challenges for the compact city as a sustainable urban form: household consumption of energy and transport in eight residential areas in the greater Oslo region. *Urban studies*, *42*(12), 2145-2166.

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).

Horton, F. E., & Reynolds, D. R. (1971). Effects of urban spatial structure on individual behavior. *Economic Geography*, *47*(1), 36-48.

ISPRA 2014, Italian Greenhouse Gas Inventory 1990-2012, National Inventory Report 2014, available online at http://www.sinanet.isprambiente.it/it/sia-ispra/serie-storiche-emissioni/national-inventory-report-2012/at_download/file

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

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

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

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

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

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 A*, *43*(9), 2143.

Mumford, L. (1956). *The natural history of urbanization*. Chicago & London: University of Chicago Press.

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

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), 275–295.

OECD (2012). *Compact city policies. A comparative assessment*, OECD Green Growth Studies, OECD Publishing.

Oke, T. R. (1973). City size and the urban heat island. *Atmospheric Environment (1967)*, *7*(8), 769-779.

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*, Riverhead.

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

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), 377-396.

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

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), 1879-1897.

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

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), 382-392.

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

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

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

APPENDIX: Regression results

Transport emissions

Table A.1: 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 A.2: 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 A.3: 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 A.4: 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	

House heating emissions

Table A.5: 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 A.6: 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 A.7: 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 A.8: PM_{10} house heating: per capita emissions

	signif.	*2000-2005*			*1990*	
		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	

Discussion Papers
Collana del Dipartimento di Economia e Management, Università di Pisa (ISSN: 2039-1854)